THE CALIFORNIA EARTHQUAKE OF APRIL 18, 1906

REPORT

OF THE

STATE EARTHQUAKE INVESTIGATION COMMISSION

IN TWO VOLUMES AND ATLAS

VOLUME I, PART I

WASHINGTON, D. C.
PUBLISHED BY THE CARNEGIE INSTITUTION OF WASHINGTON
1908

THE CALIFORNIA EARTHQUAKE OF APRIL 18, 1906

REPORT

OF THE

STATE EARTHQUAKE INVESTIGATION COMMISSION

STATE EARTHQUAKE INVESTIGATION COMMISSION

THE CALIFORNIA EARTHQUAKE OF APRIL 18, 1906

REPORT

OF THE

STATE EARTHQUAKE INVESTIGATION COMMISSION

IN TWO VOLUMES AND ATLAS

VOLUME I

BY

ANDREW C. LAWSON, CHAIRMAN

IN COLLABORATION WITH G. K. GILBERT, H. F. REID, J. C. BRANNER, H. W. FAIRBANKS, H. O. WOOD, J. F. HAYFORD AND A. L. BALDWIN, F. OMORI, A. O. LEUSCHNER, GEORGE DAVIDSON, F. E. MATTHES, R. ANDERSON, G. D. LOUDERBACK, R. S. HOLWAY, A. S. EAKLE, R. CRANDALL, G. F. HOFFMAN, G. A. WARRING, E. HUGHES, F. J. ROGERS, A. BAIRD, AND MANY OTHERS

VOLUME I, PART I

WASHINGTON, D. C.

PUBLISHED BY THE CARNEGIE INSTITUTION OF WASHINGTON

1908

CARNEGIE INSTITUTION OF WASHINGTON

Publication No. 87, Volume I, Part I

Norwood Press
J. S. Cushing Co. — Berwick & Smith Co.
Norwood, Mass., U. S. A.

PREFACE.

The account of the California earthquake of April 18, 1906, contained in this report, exemplifies the spirit of coöperation which pervades the scientific work in our day. Immediately following the great shock not only was the necessity of a scientific inquiry generally perceived, but it was realized that the occasion afforded an exceptional opportunity for adding to our knowledge of earthquakes. The scientific men of the state, each on his own initiative, began the work of assembling observations; the more intelligent citizens became persistent in their inquiries as to the nature of the earthquake, its extent and intensity, and the causes in general of such terrible disasters; and the state, thru its then Governor, George C. Pardee, unified the work of scientific investigation by the appointment of a committee of eight to direct the work. This committee was appointed on April 21, 1906, and became known as the State Earthquake Investigation Commission. On May 31, 1906, the Commission submitted a "Preliminary Report" to the Governor, which was printed and very generally distributed. In this report the details of the organization of the Commission, the program of its work, and the results attained to that date are set forth. But while the Commission acted under the authority of the Governor of the State, no money was provided by the Government for the conduct of its work. The embarrassment arising from this lack of funds was relieved about June 1, 1906, by a subvention from the Carnegie Institution of Washington, which enabled the Commission to prosecute its work as it had been planned.

About the end of the year 1906, the greater part of the observational data having been collected, the work of sifting, coördinating, compiling, and editing the same devolved upon the Chairman of the Commission. The results of this work, including several special papers by various investigators, are contained in Volume I, parts I and II, of the report and in the twenty-five maps of the accompanying atlas. In this volume especial effort has been made to give due credit to every contributor, whether he be a scientific writer discussing some particular phase of the general problem, or a citizen assisting with local information. In all cases where there is no ascription of authorship the Chairman of the Commission is responsible for the statements made. The multiplicity of contributors has made it inconvenient to duplicate their names in the already lengthy table of contents.

In general, Volume I is a record of observations with quite subordinate discussion of the facts recorded. The effort to condense the record as far as possible has been tempered by the desire to omit no significant fact, so that the record may be as complete as possible for purposes of comparison with similar events which may occur in years to come. In the preparation of this volume the Chairman of the Commission gratefully acknowledges the kind advice and cordial assistance of Messrs. G. K. Gilbert and H. F. Reid. The Commission is also under great obligation to its Secretary, Mr. A. O. Leuschner, for his very efficient services.

Volume II is chiefly a discussion of instrumental records and of the data bearing upon the mechanics of earthquakes, by Mr. H. F. Reid, who also contributes a general

discussion of the theory of the seismograph, which is the first to appear in English. Accompanying this volume are many seismograms of the earthquake, which appear in the general atlas. These seismograms are records of the shock as registered at almost all the seismological stations the world over, and are published at the suggestion of the International Seismological Association for purposes of comparison with one another, to the end that the best recording devices may be generally adopted, and also for comparison with the similar series of seismograms of the Valparaiso earthquake of August 16, 1906, which has been published by the Association.

ANDREW C. LAWSON,
Chairman State Earthquake Investigation Commission.

BERKELEY, May 31, 1908.

CONTENTS.

PART I.

PART II.

LIST OF ILLUSTRATIONS.

LIST OF MAPS AND SEISMOGRAMS IN ACCOMPANYING ATLAS.

MAPS.

No.

1. Geomorphic map of California and Nevada with parts of Oregon and Idaho, showing diastrophic character of relief, the steep descent from the subcontinental shelf to floor of the Pacific, and the more important faults of California.
2. Map of a part of the coast of California, etc.
3. Detail map of a typical part of San Andreas Rift near Fort Ross, Sonoma County, California, showing geomorphic features and trace of fault.
4. Map of region about San Francisco Bay, etc.
5. Map of part of San Francisco, etc.
6. Map of California, Mount Pinos Quadrangle.
7. Map of California, Tejon Quadrangle.
8. Map of California, Palmdale Quadrangle, of the U. S. Geological Survey, showing San Andreas Rift.
9. Map of California, Rock Creek Quadrangle.
10. Map of California, San Antonio Quadrangle.
11. Map of California, Hesperia Quadrangle.
12. Map of California, San Bernardino Quadrangle.
13. Map of California, Redlands Quadrangle.
14. Map of California, San Gorgonio Quadrangle.
15. Map of California, San Jacinto Quadrangle.
16. Map of the City of Santa Rosa, Sonoma County, California, showing parts destroyed by earthquake of April 18, 1906, and fire consequent thereto.
17. Geological map of the City of San Francisco.
18. Geological profiles with corresponding intensity curves across the City of San Francisco.
19. Map showing distribution of apparent intensity of the earthquake shock.
20. Map of the City of San Francisco, showing streets and burnt area, 1906.
21. Map of California, San Mateo Quadrangle, of the U. S. Geological Survey, showing distribution of apparent intensity, known faults, and routes examined.
22. Map of California, Santa Cruz Quadrangle, of the U. S. Geological Survey, showing distribution of apparent intensity, known faults, routes examined, and numbered localities referred to in the text.
23. Map of California and Nevada, showing distribution of apparent intensity in region affected by the earthquake of April 18, 1906.
24. Map of Coast Range region of Middle California, showing distribution of earth movement on April 18, 1906, as revealed by displacement of triangulation stations of the Coast and Geodetic Survey, as determined by resurvey, 1906–1907.
25. Distribution of the earth movement on April 18, 1906, and in 1868, as revealed by displacement of triangulation stations of the Coast and Geodetic Survey, as determined by resurvey in 1906–1907.

SEISMOGRAMS.

SHEET NO.

1. Toronto, Canada; Victoria, Canada; Baltimore, Md.; Coimbra, Portugal; San Fernando, Spain; Pilar, Argentina; Calcutta, India; Kew, England; Paisley, Scotland; Ponta Delgada, Azores; Bidston, England; Edinburgh, Scotland; Cape of Good Hope, Africa; Cairo, Egypt.
2. Irkutsk, Siberia (Milne instrument); Island of Mauritius; Perth, Australia; Honolulu, H. I.; Wellington, N. Z.; Kodaikanal, India; Bombay, India; Taschkent, Turkestan (Repsold-Zöllner instrument); Kremsmunster, Austria.

2. *a.* — Irkutsk, Siberia (Repsold-Zöllner instrument); Uccle, Belgium.

3. Berkeley, Cal.; San Jose, Cal.; Yountville, Cal.; Cleveland, Ohio; Oakland, Cal.; Los Gatos, Cal.; Alameda, Cal.; Mt. Hamilton, Cal.; Carson City, Nevada.
4. Manila, P. I.; Potsdam, Germany (Von Rebeur-Paschwitz instrument).
5. Munich, Germany; Potsdam, Germany (Wiechert pendulum); Kobe, Japan.
6. Florence, Italy.

SHEET NO.

7. Shide, England (heavy horizontal pendulum); Porto D' Ischia, Italy; Grande Sentinella, Italy; Pavia, Italy.
8. Washington, D. C.; Cheltenham, Md.; Albany, N. Y.; Porto Rico, W. I.
9. Vienna, Austria; Upsala, Sweden; Tacubaya, D. F. Mex.
10. Jurjew, Russia; Ottawa, Canada.
11. Sitka, Alaska; Tokyo, Japan; Jena, Germany.
12. Göttingen, Germany; Shide, England (Milne instrument, open scale); Messina, Italy.
13. Sofia, Bulgaria; Krakau, Austria; Irkutsk, Siberia (Bosch-Omori instrument); Taschkent, Turkestan (Bosch-Omori instrument); Catania, Italy.
14. Rocca di Papa, Italy; Granada, Spain; Strassburg, Germany.
15. Zi-ka-wei, Shanghai, China; Osaka, Japan; Taihoku, Formosa; Batavia, Java; Sarajevo, Bosnia; Calamate, Greece; Bombay, India (Coloba horizontal pendulum).

THE CALIFORNIA EARTHQUAKE OF APRIL 18, 1906.

INTRODUCTION.

On the morning of April 18, 1906, the coastal region of Middle California was shaken by an earthquake of unusual severity. The time of the shock and its duration varied slightly in different localities, depending upon their position with reference to the seat of the disturbance in the earth's crust; but in general the time of the occurrence may be stated to be $5^h\ 12^m$ A. M. Pacific standard time, or the time of the meridian of longitude 120° west of Greenwich; and the sensible duration of the shock was about one minute.

The shock was violent in the region about the Bay of San Francisco, and with few exceptions inspired all who felt it with alarm and consternation. In the cities many people were injured or killed, and in some cases persons became mentally deranged, as a result of the disasters which immediately ensued from the commotion of the earth. The manifestations of the earthquake were numerous and varied. It resulted in the general awakening of all people asleep, and many were thrown from their beds. In the zone of maximum disturbance persons who were awake and attending to their affairs were in many cases thrown to the ground. Many persons heard rumbling sounds immediately before feeling the shock. Some who were in the fields report having seen the violent swaying of trees so that their top branches seemed to touch the ground, and others saw the passage of undulations of the soil. Several cases are reported in which persons suffered from nausea as a result of the swaying of the ground. Many cattle were thrown to the ground, and in some instances horses with riders in the saddle were similarly thrown. Animals in general seem to have been affected with terror.

In the inanimate world the most common and characteristic effects were the rattling of windows, the swaying of doors, and the rocking and shaking of houses. Pendant fixtures were caused to swing to and fro or in more or less elliptical orbits. Pendulum clocks were stopt. Furniture and other loose objects in rooms were suddenly displaced. Brick chimneys fell very generally. Buildings were in many instances partially or completely wrecked; others were shifted on their foundations without being otherwise seriously damaged. Water or milk in vessels was very commonly caused to slop over or to be wholly thrown from the vessel. Many water-tanks were thrown to the ground. Springs were affected either temporarily or permanently, some being diminished, others increased in flow. Landslides were caused on steep slopes, and on the bottom lands of the streams the soft alluvium was in many places caused to crack and to lurch, producing often very considerable deformations of the surface. This deformation of the soil was an important cause of damage and wreckage of buildings situated in such tracts. Railway tracks were buckled and broken. In timbered areas in the zone of maximum disturbance many large trees were thrown to the ground and in some cases they were snapt off above the ground.

The most disastrous of the effects of the earthquake were the breaking out of fires and, at the same time, the destruction of the pipe systems which supplied the water necessary to combat them. Such fires caused the destruction of a large portion of San Francisco, as all the world knows; and they also intensified the calamity due to the earthquake at Santa Rosa and Fort Bragg. The degree of intensity with which the earthquake made itself felt by these various manifestations diminished with the distance from the seat of disturbance, and at the more remote points near the limits of its sensibility it was perceived only by a feeble vibration of buildings during a brief period.

The area over which the shock was perceptible to the senses extends from Coos Bay, Oregon, on the north, to Los Angeles on the south, a distance of about 730 miles; and easterly as far as Winnemucca, Nevada, a distance of about 300 miles from the coast. The territory thus affected has an extent, inland from the coast, of probably 175,000 square miles. If we assume that the sea-bottom to the west of the coast was similarly affected, which is very probably true, the total area which was caused to vibrate to such an extent as to be perceptible to the senses was 372,700 square miles. Beyond the limits at which the vibrations were sufficiently sharp to appeal to the senses, earth waves were propagated entirely around the globe and were recorded instrumentally at all the more important seismological stations in civilized countries.

The various manifestations of the earthquake above cited, including the cracking and deformation of the soil and incoherent surface formations, were the results of the earth jar, or commotion in the earth's crust. The cause of the earthquake, as will be more fully set forth in the body of this report, was the sudden rupture of the earth's crust along a line or lines extending from the vicinity of Point Delgada to a point in San Benito County near San Juan; a distance, in a nearly straight course, of about 270 miles. For a distance of 190 miles from Point Arena to San Juan, the fissure formed by this rupture is known to be practically continuous. Beyond Point Arena it passes out to sea, so that its continuity with the similar crack near Point Delgada is open to doubt; and the latter may possibly be an independent, tho associated, rupture parallel to the main one south of Point Arena. It is most probable, however, that there is but one continuous rupture. The course of this fissure for the 190 miles thru which it has been followed is nearly straight, with a bearing of from N. 30° to 40° W., but with a slight general curvature, the concavity being toward the northeast, and minor local curvatures. The fissure for the extent indicated follows an old line of seismic disturbance which extends thru California from Humboldt County to San Benito County, and thence southerly obliquely across the Coast Ranges thru the Tejon Pass and the Cajon Pass into the Colorado Desert. This line is marked by features due to former earth movements and will be referred to in a general way as a *rift*, the term being adopted from the usage for analogous features in Palestine and Africa.[1] To distinguish it from other rifts of similar origin, it will be referred to more specifically as the San Andreas Rift, the name being taken from the San Andreas Valley on the peninsula of San Francisco, where it exhibits a strongly pronounced character and where its diastrophic origin was first recognized in literature.

The plane or zone on which the rupture took place is, so far as can be determined from a study of the surface phenomena, nearly vertical; and upon this vertical plane there occurred a horizontal displacement of the earth's crust or at least of its upper part. The displacement was such as to cause the country to the southwest of the rift line to be moved northwesterly relatively to the country on the northeast side of that line. The differential displacement in a horizontal direction was probably not less than 10 feet for the greater part of the Rift; in many places it measured over 15 feet, and in one place as much as 21 feet.

[1] Roy. Geograph. Soc. vol. IV, 4, 1894. The Great Rift Valley, by J. W. Gregory, London, 1896.

This differential displacement of the earth's crust along the plane of rupture constitutes a *fault*, and will be so referred to in the text of the report. It is named the San Andreas fault. The intersection of the fault plane or narrow zone with the surface of the ground is manifested by cracks, heaved sod, scarps, etc., and these manifestations are designated the *fault-trace*. As a result of this fault, all the fences, roads, railways, bridges, tunnels, dams, pipes, and other structures which crost its path were dislocated. All property lines and other survey lines which were intersected by it were offset. Inasmuch as the movement of the earth which caused the fault was not confined to its immediate vicinity, but was distributed over a considerable belt of country on either side of the trace of the rupture, the latitudes and longitudes of a large portion of the Coast Ranges of California were changed, and the triangles established by the Coast and Geodetic Survey in its triangulation of the region were distorted.

In addition to the horizontal displacement there was, particularly toward the northern end of the fault, a vertical displacement probably nowhere exceeding 2 to 3 feet, whereby the country to the southwest was raised relatively to that to the northeast. In many places, however, particularly toward the southern end of the fault, no vertical displacement can be detected; and there is some indication that, if there was vertical displacement in this region, it was the reverse of that observed in the northern portion of the fault. This rupture of the earth's crust gave rise to certain manifestations at the surface which resemble those described above as a result of the vibratory commotion of the earth, due to the sudden displacement. The cracking and rending of the surface along the line of the fault is a direct expression of the rupture and displacement which originated the earthquake, whereas the cracks, fissures, and lurching of the soft bottom lands and the landslide cracks on the hillsides, whether near the fault line or remote from it, are referable to the oscillation of the crust. The two classes of phenomena must, therefore, be discriminated, particularly as there has been a tendency on the part of some observers to class the secondary phenomena with the primary and interpret the former as indicative of fault lines in the earth's crust, when in reality they are merely superficial phenomena.

While the shock was perceptible to the senses to the extent above indicated in California, Nevada, and Oregon, the distribution of the higher grades of intensity was remarkably linear and was definitely related to the fault line, and to the general trend of the coast of California. This may be brought out in a preliminary way by stating that a zone of destructive effects extends parallel to the Rift from Humboldt Bay, in Humboldt County, to the vicinity of King City in Monterey County, a distance of 350 miles. If we take the throw of brick chimneys and allied phenomena as indicating the limits of what may be called destructive effects, the width of this zone may be fairly approximated at about 70 miles, or about 35 miles on either side of the fault, or its prolongation where no actual fault is observable at the surface. The length of this zone of destruction is thus five times greater than its width, and the total area within which the shock was sufficiently severe to throw brick chimneys may be placed at something over 25,000 square miles; it being assumed that the severity to the southwest of the fault, beneath the waters of the Pacific, was equal to that on the land. If the fault near Point Delgada be regarded as distinct from that extending from Point Arena southeasterly, then the total area of these high intensities would be considerably larger in the direction of the Pacific.

Within this outer limit of destructive effects the intensity increased toward the fault. But proximity to the fault was not the only factor determining the degree of intensity. The soft, more or less incoherent, and water-saturated alluvial formations of the valley-bottoms were much more severely shaken than the rocky slopes of the intervening ridges, and the structures upon them were consequently more commonly and more completely wrecked. It is not understood by this excessive damage on the valley-

bottoms that the vibratory movement due to the passage of the earth-wave was characterized by greater energy than where it traversed elastic rocks; but that this energy was manifested in a form of movement more destructive to structures upon the surface. The intensity of the shock upon the valley-bottoms, as inferred from damage, seemed abnormally high. In terms of energy it was probably not abnormal. It thus became necessary to discriminate between *apparent intensity* and *real intensity.* Inasmuch as we have to deal primarily with observable effects and record these as a basis for inference, it has been found convenient to use the term "apparent intensity" in a technical sense thruout the report; and all the grades of intensity specified, even when the qualification "apparent" is omitted because of the wearisomeness of its reiteration, are grades of "apparent intensity" arrived at by applying literally the criteria of the Rossi-Forel scale.

GEOLOGY OF THE COAST SYSTEM OF MOUNTAINS.

DEFINITIONS.

In common with many other mountainous tracts the world over, the Coast System has limits which are difficult of precise definition. The criteria which serve to discriminate one tract from another are various and have different values in different cases. Any attempt at precise definition must be more or less arbitrary. An outline of the extent and subdivisions of the system will, however, be presented in summary fashion.

On the north the Coast System extends to the northern end of Humboldt County, and in that county and in southern Trinity County the last typical ridge is South Fork Mountain. This is a remarkably linear ridge beginning near the coast and extending with a northwest-southeast course to the vicinity of North Yallo Bally Mountain. Beyond South Fork Mountain to the northeast lie the Klamath Mountains, a group more nearly allied in the history of its uplift and in its constituent rocks to the Sierra Nevada than to the Coast Range. On the south the Coast System is sometimes regarded as ending in Santa Barbara County; and the mountains of Southern California, thence east-southeast and south to the Mexican boundary, are regarded as a distinct system, being viewed as a northerly prolongation of the orographic axis of the peninsula of Lower California. The chief consideration favoring this distinction is the change in trend of the mountain ridges, which becomes apparent just north of the Santa Barbara Channel. Other facts favor this discrimination, such as the prevailing absence of the Franciscan formations in the mountains of southern California and the greater abundance of granitic rocks; but more especially the greater incisiveness of the structural lines, indicating, on the whole, more intense orogenic action. But these considerations are largely offset by the unmistakable continuity of the tectonic lines of the northern ranges into the mountains of southern California, and by the fact that the movements to which their larger features are due date from the close of the Tertiary. It would seem, therefore, that there is sufficient unity of character in these coastal mountains, in spite of their change of trend, to warrant their being classed as the Coast System from South Fork Mountain south to the Mexican boundary and beyond. That term may be used in a comprehensive sense, significant of the genetic and structural unity which runs thru them.

It will nevertheless be very convenient to recognize three subdivisions of the Coast System thus outlined. The first of these subdivisions extends from South Fork Mountain on the north to the Valley of the Cuyama River on the south, and may, in accordance with popular usage, be referred to simply as the Coast Ranges, the term "system" being used only when it is intended to express the more comprehensive view. The second subdivision is a broad chain extending from Santa Barbara County to the far side of the Colorado desert with a general trend of west northwest-east southeast, and including the San Rafael, Santa Ynez, Santa Susannah, Santa Monica, San Gabriel, and San Bernardino Ranges, and also, perhaps, the Chocolate Range. This chain is sometimes referred to as the Sierra Madre, tho the full application of the term in popular usage is not clear. The third subdivision embraces the mountainous country south and southeast of the valley of Southern California, the principal ranges of which are the Santa Ana and the San Jacinto. These have the northwest-southeast trend of the Coast Ranges and, in accordance with the suggestion of some of the earlier writers on Californian geology, may be referred to as the Peninsular chain.

GEOLOGICAL HISTORY.

The Coast Ranges of California have had a long and varied geological history. Their structure is complex and the sequence of formations differs at different points. Several of the more important groups of sedimentary rocks contain, so far as known, but few fossils or none at all. Only in recent years have the topographic maps necessary for an adequate study of the stratigraphy and structure of the region become available, and then only for limited areas. Nevertheless the general outlines of the geology of the Coast Ranges are known, and in some of the localities which have been topographically mapped, a considerable body of detailed information is at hand.

The oldest sedimentary rocks of the Coast Ranges are of unknown age. They comprize impure and somewhat magnesian limestone, quartzites, and various crystalline schists. The limestones are usually in the form of coarse marble varying in color from dark gray to white and containing frequently some graphite and less commonly lime silicate. The quartzites are thoroly indurated, as a rule, sometimes to the extent of being vitreous, and usually show well-marked stratification. The schists have as yet been little studied, and no adequate observations upon their character in detail have been put on record. They are known, however, to comprize both micaceous and hornblendic varieties.

These marbles, quartzites, and crystalline schists are known only in more or less fragmentary form, associated with considerable bodies of granitic rocks which have invaded them as batholiths. The most common occurrence of the marbles, quartzites, and schists is in the form of limited belts and isolated patches embedded in the granitic rocks, or in limited areas flanking the margins of the batholiths, and showing evidence of contact metamorphism. It is evident in most cases, and is probably generally true, that the granite of the Coast Ranges is of later date than the metamorphic sedimentary rocks associated with them. While the age of these pregranitic sedimentary formations is at present unknown, the age of the granite is suggested by its seeming identity with the granite of the Sierra Nevada. The latter is a vast batholith known to be intrusive in Paleozoic and Mesozoic strata as late as the Upper Jurassic. This granite has been followed thru the Sierra Nevada to Tehachapi and Tejon Pass, where the range curves sharply around and passes into the Coast Ranges. Passing northerly thru the Coast Ranges, granite identical in character with that of the Sierra Nevada, and carrying identical inclusions of older sedimentary rocks, is traceable in more or less extensive areas from the upper reaches of the Cuyama River to Bodega Head on the coast north of the Golden Gate. It thus seems probable that the granite of the Coast Ranges, like that of the Sierra Nevada, is of late Jurassic or post-Jurassic age. The granitic rocks of the Coast Ranges, together with the pregranitic rocks into which they are irruptive, constitute a complex which is thus the probable analogue of the Bedrock Complex of the Sierra Nevada.

This Coast Range Complex was subjected to vigorous erosion and then submerged to serve as the sea floor upon which the series of rocks known as the Franciscan was deposited. This series consists for the most part of medium-coarse, dark gray or greenish-gray sandstone, strongly indurated, with subordinate shales and conglomerates. Intercalated with these sandstones are important horizons of foraminiferal limestone and radiolarian chert and admixtures of volcanic rocks, chiefly basaltic in character. In the vicinity of the Bay of San Francisco, where the series is best known, it falls into seven stratigraphic divisions. These are in ascending order:

(1) A group of arkose sandstones with some conglomerates and shales reposing unconformably upon the Montara granite and with an aggregate thickness of about 800 feet.

(2) A formation of light-gray, very compact and fine-textured foraminiferal limestone ranging in thickness from about 60 to possibly a few hundred feet.

(3) Sandstones aggregating 2,000 feet in thickness.
(4) A formation of radiolarian cherts from 100 to 900 feet.
(5) Sandstone, 1,000 feet.
(6) Radiolarian cherts, 500 feet.
(7) Sandstone, 1,400 feet.

In this sequence of sedimentary strata, particularly toward its upper part, there are intercalated lavas at various horizons.

After their accumulation, but before the next higher series of rocks was deposited upon them, the Franciscan strata were invaded by intrusive rocks at points so numerous and so widespread thruout the Coast Ranges that these intrusive bodies constitute one of their most characteristic associations, in contrast to the series which succeed them. The intrusive rocks are of two general types. One is a highly magnesian rock, usually a peridotite, but with facies of pyroxenite and gabbro, the peridotite being generally almost completely serpentinized. The other is a basaltic rock grading into diabase and having in many of its occurrences the peculiar structure characteristic of the spheroidal basalts. In addition to the spheroidal structure on the gross scale, it is in some cases variolitic. Associated with both of these intrusives are areas, generally of limited extent and sporadic distribution, of glaucophane and other crystalline schists, which appear, where they have been most thoroly studied, to be the result of a peculiar kind of contact metamorphism.

The stratigraphic composition of the Franciscan series indicates an interesting to-and-fro migration of the shore line of that time, probably due to a vertical oscillation of the continental margin. The basal group of sandstones, shales, and conglomerates is clearly a terrigenous deposit laid down in proximity to the margin of the continental area from which the sediments were derived. The next succeeding formation, the foraminiferal limestone, on the contrary, is nonterrigenous. Its character as nearly pure carbonate of lime, except for the flinty lenses and nodules it contains, and the abundance of foraminifera, indicates that the sea-bottom over the present position of the San Francisco Peninsula was too remote from the shore to receive an admixture of sand or clay. That is to say, the conditions which favored the deposition of the limestone were inaugurated by a withdrawal of the shore line from the position which it occupied during the deposition of the underlying sandstones. And this lateral migration of the shore was doubtless the result of a sinking of the coast.

Above the foraminiferal limestone sandstones again occur, indicating a return of the shore to about its former position, doubtless due to an uplift of the sea-bottom and coast. These sandstones are in turn followed by a nonterrigenous formation of radiolarian cherts. These are for the most part flinty rocks containing abundant remains of radiolaria, marine organisms which secrete a siliceous test instead of a calcareous one, as in the case of the foraminifera. They contain no admixture of sand, and the shaly partings which separate the layers of chert are very doubtfully referable to land waste. Here again the sea bottom must have been deprest and the shore line caused to withdraw. These radiolarian cherts are followed again by sandstones, and these by a second formation of radiolarian cherts, the former as before indicating uplift of the sea-bottom and the latter depression. The last movement in Franciscan time was uplift, indicated by the sandstones, which rest upon the second horizon of radiolarian cherts and which constitute the topmost formation of the Franciscan series.

The age of the Franciscan is not positively known. Certain general considerations, however, contribute data upon which a tentative judgment as to this question may be based. Stratigraphically, the Franciscan lies upon the eroded surface of the Coast Range granites, the correlation of which with the post-Jurassic granites of the Sierra Nevada has been suggested. If such correlation be adopted, the age of the Franciscan must be

post-Jurassic. On the other hand, the Franciscan is clearly pre-Knoxville; and the Knoxville has usually been regarded as the local base of the Cretaceous. Fossils are scarce in the Franciscan, but such fragmentary forms as have thus far been found point to a Cretaceous age. It would seem not improbable, therefore, that the Franciscan represents a pre-Knoxville division of the Cretaceous, which has not as yet been recognized in the geological scale. The question, however, requires further investigation before a final decision can be reached.

After the accumulation of the Franciscan strata as thus characterized, and perhaps in connection with the invasion of the series by peridotitic and basaltic intrusives, the region was folded and broken, and elevated within the zone of erosion. The elevatory movement was probably quite general. The Franciscan, while subjected to general denudation, was probably nowhere stript down to the underlying basal complex before it was submerged to receive the next succeeding sedimentary strata. These comprize the Knoxville formation, consisting wholly of shales and sandstones with quite subordinate layers and lenses of limestone, all in very regular and rather thin strata, significant of deposition in a shallow basin under fluctuating conditions of transportation. The Knoxville varies in volume from a few hundred to several thousand feet and is widely distributed over the Coast Ranges. It is succeeded in the vicinity of the Bay of San Francisco, and to a less marked degree in other parts of the Coast Ranges, by a formation of coarse conglomerate known as the Oakland conglomerate. This conglomerate attains a thickness of over 1,000 feet in places and follows the Knoxville shales in apparently conformable sequence. The change in the character of the deposits from shales to coarse conglomerates, without any interruption in the continuity of sedimentation, suggests an orogenic disturbance of the margins of the basin within which the Knoxville beds were accumulating, whereby the grades of the streams were greatly accentuated and the degradation of the continental region correspondingly accelerated.

The Oakland Conglomerate, or, where that is missing, the Knoxville shale, is directly followed by a formation of thick bedded sandstones and shales known as the Chico formation. It has a thickness in places of many thousands of feet. The entire volume of strata, from the base of the Knoxville to the top of the Chico, is usually referred to as the Shasta-Chico Series, the Shasta comprizing the Knoxville and Oakland formations, together with certain other paleontological subdivisions not here particularly mentioned. The series is remarkable for its great volume. In the northern Coast Ranges to the west of the Sacramento Valley, the thickness of the sedimentary section, comprizing practically only sandstones and shales, is as much as 29,000 feet. This vast accumulation of strata clearly signifies the development of a great geosyncline, or depression of the sea-bottom in that region in which deposition kept pace with subsidence thruout this portion of Cretaceous time. The Shasto-Chico series is usually regarded as comprizing the whole of the California Cretaceous, but the considerations cited above in regard to the Franciscan indicate that the latter may perhaps be included in the lower Cretaceous section of this region.

The movements which brought the Mesozoic to a close and inaugurated the Tertiary in the Coast Range region were not those of violent orogenic deformation such as characterize this period of geological time in many other parts of the world; but were rather of the nature of a partial elevation of the region, with quite gentle deformation, resulting in a notable restriction of the basin of deposition. The earliest Eocene strata show no marked structural discordance with the Chico. It is nevertheless very probable that a notable unconformity exists, since the abundant and characteristic Cretaceous fauna disappeared and was supplanted by an almost totally distinct assemblage of life forms. The Eocene of the California Coast Ranges falls into two paleontologically distinct groups which have been classed together as the Karquines series. The lower of these

comprizes about 2,000 feet of sandstones, portions of which are green sands, together with some shales. These make up the Martinez group. Its distribution, so far as known at present, is quite limited and is confined to the middle Coast Ranges on their eastern side, between Clear Lake and Mount Diablo. The upper division of the Karquines is known as the Tejon group, and comprizes also about 2,000 feet of sandstones, often somewhat ferruginous and weathering reddish, but very strongly cemented. The Tejon strata are apparently conformable upon the Martinez, but the sharp contrast in the faunal contents of the two groups suggests rather widespread physiographic changes at the close of the Martinez which may be regarded as indicative of unconformity. The Tejon strata are much more widely distributed than the Martinez, a fact which suggests the enlargement of the Karquines basin of deposition by subsidence of the coast during the progress of Eocene time.

The next succeeding group of rocks, belonging to the Oligocene division of the Tertiary, has been named the San Lorenzo Formation.[1] It is known in Santa Cruz County, where it attains a thickness of 2,300 feet, made up chiefly of gray shales and fine sandstones. Its stratigraphic relations to the Tejon are not yet known, but its fauna is said by Arnold to contain many species which appear to be closely related to Tejon forms. It may thus be considered as following the Tejon conformably. It is in certain sections known to be unconformable beneath the oldest formation of the Miocene, known as the Vaqueros Sandstone, indicating that after the deposition of the San Lorenzo formation, the region of the Coast Ranges was disturbed and uplifted into the zone of erosion; and the following facts regarding the transgression of the Miocene Sea indicate that this uplift was a very extensive one. Such an uplift in time immediately preceding the Miocene is further indicative of a much closer relationship between the San Lorenzo and the Tejon than between the former and the Monterey.

Miocene time in the Coast Range region was characterized by a progressive subsidence with oscillations of the coast. The Miocene sea gradually transgrest the continental margin from the southwest, and as it did so spread a formation of arkose sands and conglomerates over the greater part of the southern Coast Ranges. This was followed, as the water deepened with progressive subsidence, by a remarkable deposit of bituminous shales. These shales are usually whitish or cream-colored, tho often of a purplish or other dark tint, and may be either of a soft chalky consistency, or opaline, or hard and flinty. It is thruout an essentially siliceous formation and is largely diatomaceous in character, tho more or less admixt with volcanic pumiceous ash. In some portions the ash is a prominent constituent, and in San Luis Obispo County there is a deposit aggregating about 1,000 feet in thickness of well-stratified volcanic tuff and agglomerate. In San Mateo County there are basalts which were erupted at this period. Interstratified with these siliceous shales, thin beds of more or less ferruginous and somewhat magnesian limestones are by no means uncommon. They are, however, lenticular or nonpersistent, and are of a very compact texture and usually nonfossiliferous. There are also in some places thin but persistent beds of a peculiar, very hard, fine-grained, light-colored sandstone intercalated with the shales. In the southern portion of the Coast Ranges the bituminous shales accumulated to a thickness of several thousand feet, but in the middle Coast Ranges, in the vicinity of the Bay of San Francisco, the Miocene sea was characterized by an oscillatory or to-and-fro migration of its eastern shore line, due to alternate uplift and subsidence of the coast, quite analogous to that described for the Franciscan period. This gave rise to an alternation of shallow water in which sandstones were deposited, and deep water in which siliceous ooze accumulated with but little admixture of terrigenous material. We have thus in the territory between Mount Diablo and the Bay of San Francisco an alternation of four formations of bituminous

[1] Arnold, U. S. G. S. Professional Paper No. 47, p. 16.

shale with five formations of sandstone, the latter being at the bottom and top of the series. The series is known as the Monterey series, and its various members have distinctive formational names. While the oscillation of the coast so clearly recorded in the strata near the Bay of San Francisco is not apparent in the southern Coast Ranges, it is by no means certain that they were not affected in a similar way. The vertical movement involved was not great, and such a movement might have extended over the deeper portions of the area of deposition in Monterey time without effecting a sufficient change in the depth of the water to alter the character of the sediments. The Monterey sea apparently did not, even at the time of its maximum transgression, extend far over the region of the northern Coast Ranges, and a line drawn from Tehachapi to Cape Mendocino would probably represent the general position of the shore at the close of Monterey time.

At the close of the Miocene, the Coast Range region was disturbed by orogenic movements and uplifted into the zone of erosion. It was then deprest irregularly so as to give rise to local basins of sedimentation in which accumulated great thicknesses of Pliocene beds, particularly about the Bay of San Francisco and southward. The oldest of these Pliocene formations is the San Pablo, which lies unconformably upon the Monterey strata. This is essentially a sandstone formation with a thickness of from 1,000 to 2,000 feet. It occurs on both sides of the Coast Ranges from the vicinity of the Bay of San Francisco southward and appears to have been laid down in two basins, separated by a barrier corresponding to the general axis of the present Coast Ranges. The formation on the east side of the range is characterized by a notable admixture of dark andesitic ash, which gives the unweathered exposures of the sandstones a distinctly blue color. This formation has a fauna of over 100 species, of which more than 40 per cent are living forms. This fact, and the unconformable superposition of the formation upon the Monterey, are warrant for placing it in the Pliocene. On the west side of the Coast Ranges, the San Pablo is best known in San Luis Obispo and Santa Barbara Counties, and is there free from volcanic admixtures, tho the basal beds are very commonly characterized by the presence of asphaltum, which cements the sand together and constitutes the well-known bituminous rock of the region. This asphaltum appears to have originated in part as a seepage from the upturned bituminous shale of the Monterey along the shores of the San Pablo sea, and molluscan remains of San Pablo age are often embedded in it.

Succeeding the San Pablo, but nowhere, so far as the writer is aware, reposing directly upon it, is the Merced series. The sediments composing this series were laid down in rather acute geosynclinal troughs, resulting from orogenic deformation of the coast in middle Pliocene time. Three of these troughs are known. The most northerly is that now occupied by the Valley of the lower Eel River in Humboldt County; the second is largely occupied by the Santa Rosa Valley in Sonoma County; the third is on the Peninsula of San Francisco, extending thence south to the coast of Santa Cruz County. The Merced strata in the Valley of the lower Eel River, and the typical Merced section near San Francisco, show each a thickness of something over a mile. In Sonoma County the marine Merced beds grade eastward into fluviatile conglomerates, admixed with volcanic ashes. The maximum thickness is about 3,500 feet. The lower part of the series is here characterized by a considerable volume of white volcanic pumiceous tuffs, which thinout rapidly to the westward. These were in part laid down directly on a land surface, burying forests of huge sequoia, whole trees being now completely silicified.[1] On the coast of Santa Cruz County, the series is represented by strata of lower stratigraphic horizons than nearer San Francisco, these lower beds having been called the Purissima formation, altho the sedimentation was continuous with that of the Merced. The

[1] For a description of the Merced beds of Sonoma County and the underlying pumiceous tuff, a paper by V. C. Osmont, Bull. Dept. Geol., Univ. Cal., vol. 4, No. 3, should be consulted.

lower horizon of the beds on the Santa Cruz Coast, as compared with the beds nearer San Francisco, indicates a transgression of the Merced sea from the south. The upper portion of the Merced section contains so large a proportion of molluscan remains of existing species that it has been regarded by Arnold as Pleistocene rather than Pliocene.

The accumulation of the Merced series to the great thickness above indicated in middle and northern California proves local depressions of the coast of over a mile below sea level in later Pliocene time. Similar orogenic deformation was in progress at the same time on the eastern side of the barrier corresponding to the then axis of the Coast Ranges. These movements gave rise to great troughs from which the sea was excluded, but which were occupied by fresh water, and filled with sediments equal in volume to those of the marine troughs to the west of the barrier. The greater part of these fresh-water beds are comprized in the Orindan formation, which may be the equivalent of the Cache Lake beds of the Clear Lake district [1] and of the Paso Robles in the southern Coast Ranges. They have an extensive distribution on the eastern side of the Coast Ranges, and in the vicinity of the Bay of San Francisco there intervenes between the base of the Orindan and the San Pablo a formation of white pumiceous tuff entirely similar to that at the base of the Merced series in Sonoma County, but containing here fresh-water fossils. This tuff attains a maximum thickness of about 1,000 feet and is known as the Pinole tuff. Thruout the Orindan there are occasional intercalated strata of volcanic tuff of moderate thickness. The Orindan lacustrine period was brought to a close in the region of the middle Coast Ranges by volcanic eruptions which resulted in extensive flows of lava and showers of ashes. Upon these lavas lake basins were later established and some hundreds of feet of fresh-water deposits (Siestan formation) accumulated in them, which were in turn buried by other lavas.

The accumulation of the Merced marine beds and the corresponding lacustrine and volcanic rocks was brought to a close by an acute and widespread deformation regarded as part of the general mountain-making movements which ushered in the Pleistocene in western North America. As a result of these movements, the Merced and Orindan basins were folded and faulted, and the basement upon which their contained strata had been laid down was lifted in part from a position over a mile below sea-level to one far above sea-level. The Pliocene formations were brought within the zone of active erosion and the evolution of the present geomorphic features of the Coast Ranges was inaugurated. When the degradation of the folded Orindan strata was well advanced, a lake basin was established across the edges of these strata and in it accumulated the various fresh-water beds and volcanic lavas and tuffs comprizing the Campan series. At a time within the Pleistocene when the geomorphic evolution of the coast had been well advanced to its present condition, the coastal belt was deprest 1,000 to 2,000 feet lower than it is at present, and then uplifted in stages marked by marine terraces along many parts of the coast. Since this there have been oscillations of the region about the Bay of San Francisco, the net result of which has been a depression allowing the sea to invade the valley-lands and thus make the magnificent harbor to which San Francisco owes its existence.

In the foregoing sketch of the formations of the Coast Ranges and their historical significance, it is desired to emphasize particularly the remarkable series of subsidences and uplifts which have affected the coastal region from the beginning of the Franciscan to the present. This record of oscillation is in marked contrast to the comparative stability of the Sierra Nevada. Except for a marginal strip of its foot-hill slopes, the region of the present Sierra Nevada has not been submerged beneath the sea. During the geological ages in which the Coast Range region has been repeatedly deprest to receive marine sediments, the sum of the maximal sections of which amounts to 65,000 feet of strata, the western edge of the Sierra Nevada region has probably never been

---

[1] Described by G. F. Becker, U. S. G. S. Monograph XIII, pp. 219–221, 238–242.

depress over 1,000 feet. The geological record for the latter region is in terms of degradation rather than of deposition; and such deposits as have here accumulated are referable wholly to fluviatile, lacustral, and volcanic agencies. It is thus apparent that from the point of view of the stability of the earth's crust, the Coast Range region has been very much more mobile than the Sierra Nevada. The long comparative stability of the latter was, it is true, interrupted at the close of the Tertiary by a very notable uplift, whereby it took the form of a tilted orographic block of great size and remarkable unity; but this does not detract from the force of the contrast. The difference in behavior with respect to crustal stability makes the Coast Ranges a totally distinct and different geological province from the Sierra Nevada.

Between these two strongly contrasted provinces lies the great valley of California, one of the very notable geomorphic features of the continent. This valley is but one of a long series of similar depressions which lie along the western border of the North American continent, between the coastal uplands and the western edge of the continental plateau. In the north it has its probable analogues in Hecate Strait, the Gulf of Georgia, Puget Sound, the Willamette Valley, the Ashland Valley, and the depression between the Sierra Nevada and the Klamath Mountains. On the south we see its analogues in the Colorado Desert, the Gulf of California, and in the valley which lies between the southern border of the central plateau of Mexico and the Sierra Madre del Sur. In the Californian region we must interpret the axial line of this depression as a tectonic hinge, upon which the mobile coastal region has swung in a vertical sense upon the edge of the interior plateau, here represented by the Sierra Nevada. Whether this tectonic hinge is a more or less flexible zone upon which movement has taken place without rupture, or whether it represents a zone of dislocation, is not clear; but that differential movement has taken place along the valley line is one of the salient facts in the geological history of California.

STRUCTURE.

A detailed account of the structure of the Coast System would involve a discrimination between features referable to the different orogenic movements which have affected the region at various periods of its history. Owing to this succession of movements, new structures have been superimposed upon older structures, or upon remnants of older structures, so often that the resultant effect is extremely complicated and not only difficult to unravel but difficult to state or describe in any simple way. In this summary review of the subject, no such detailed discrimination will be attempted. The only effort will be to call attention to the salient features, which are for the most part referable to the orogenic movements of later Tertiary and post-Tertiary time.

Marginal Features. — In a consideration of the structural features of the Coast System, its marginal lines on the east and west first claim attention. The eastern slope of the Coast Ranges rises from the floor of the Great Valley much more abruptly in general than does the western slope of the Sierra Nevada from the same valley floor. Turner[1] has suggested that the Great Valley east of the Coast Ranges is determined by a fault. There is some warrant for this view and it is certainly true in part. The very precipitous mountain front which rises from the valley at its southern end is without doubt a degraded fault-scarp, tho whether or not this fault or a series of similar faults can be followed along the edge of the mountains to their northern end is questionable. It is, however, safe to say that the eastern margin of the Coast Ranges represents a line of acute deformation, with the probability of that deformation having taken the form of faults in certain places. No one has yet made a sufficiently careful study of the question to make a more precise statement possible. In general, this line of acute deformation is not

[1] Am. Geologist, vol. XIII, p. 248.

straight, but is curved, with the concavity toward the northeast. Between the southern end of the valley and the vicinity of Coalinga its course is about N. 35° W. From Coalinga, where there is an offset or jog in the general trend north to Tracy, the course is about N. 30° W. From Tracy to Suisun there is a marked westerly embayment in the Coast Ranges which is probably due, in part at least, to the depression of the region about the Bay of San Francisco. From Suisun northward to the vicinity of Red Bluff the general course of the margin of the Coast Ranges is north and south. At Tejon Pass the eastern margin of the Coast System receives the abutment of the southern end of the Sierra Nevada; thence southward, with a course swinging more easterly, it determines the southwest limit of the Mojave Desert.

On the seaward side the Coast System is usually regarded as being limited by the shore line. The precipitous coast rising to elevations of from 2,000 to 5,000 feet, extending from Cape Mendocino to Point Conception, and the popular notion that mountain ranges are confined to the land areas of the earth, are justification for this view. But in a more comprehensive view, embracing all inequalities of the earth's surface both above and below the sea-level, the western margin of the mountainous area, the familiar portions of which we call the Coast System, will have to be placed farther seaward. Off the coast of California the sea-bottom slopes down to the 3,000-foot submarine contour at a moderate angle and then plunges steeply to depths of over 12,000 feet. Beyond the foot of this steep slope the sea-bottom has very flat gradients and the 15,000-foot contour is far out to sea. From the Oregon line to Point Conception the 3,000-foot submarine contour, or the brink of the steep slope, lies off shore at a distance of from 15 to 35 miles; but at Cape Mendocino and at the Bay of Monterey this line is found much closer in. South of Point Conception this steep slope has the same general trend as to the north. That is to say, it shows no embayment in its course corresponding to that at the Santa Barbara channel and southward. This is particularly true of the course of the 6,000, 9,000, and 12,000-foot contours. The slope is by no means uniform for its entire length. From Point Arena to the latitude of the Golden Gate the grade is notably steep from the 3,000 foot to the 9,000-foot contour. This is also true off Point Conception. From the latter point southeastward the steep portion of the slope is from the 6,000-foot to the 12,000-foot contour; and the same statement holds for the slope off San Simeon Bay. In general, the steepest profile lies between the 6,000 and the 9,000-foot line.

This steep drop from the subcontinental platform to the broad floor of the Pacific must be regarded as the geomorphic expression of a rather acute deformation of the earth's crust, and those portions of the slope where the contours are crowded together, as for example between Point Arena and the latitude of the Golden Gate, off San Simeon Bay, off Point Conception, and off the platform of the Channel Islands, can scarcely be interpreted as other than fault-scarps. The slopes at the localities mentioned are quite comparable to the great fault-scarp which forms the eastern front of the Sierra Nevada. At the base of the slope off the Channel Island platform, the recent dredging operations of the *Albatross* brought up from a depth of 12,000 feet numerous fragments of rock similar to the bituminous shale of the Monterey series of the southern Coast Range. With this rock was found much asphaltum. This indicates that at the base of the slope there are talus accumulations of so recent a date that they have not yet been buried by oceanic sediments.

This line of acute deformation of the crust off the entire length of the coast of California can not be ignored in any consideration of the orographic features of the region. The slope referred to is doubtless devoid of those sculptural features characteristic of mountains within the zone of erosion, and which we are too apt to look upon as essential, but it constitutes nevertheless a notable mountain front rising from the floor of the Pacific. It is the natural western boundary of the mountainous tract which we call the

Coast System. The course of this mountain front participates in the curvature, with convexity to the Pacific, observable in the land portion of the Coast Ranges, in the Great Valley of California, and in the Sierra Nevada. This convexity toward the Pacific is, it may be observed in passing, characteristic of the dominant tectonic lines about the border of that great ocean. It is very marked in the Aleutian belt, in Kuriles, in the Japanese Isles, in the festoon extending from Formosa thru the Philippines, the Moluccas, and Java to Sumatra, which is convex to both the Pacific and the Indian Oceans; and in the chain including the Salomon Islands, the New Hebrides, and New Zealand. It is also apparent in the trend of the Sierra Madre Occidental and Sierra Madre del Sur of Mexico, and in the course of the Andes thru Colombia, Ecuador, and Peru.

Having indicated the east and west boundaries of the Coast System as their dominant structural lines, we may now consider those features which pertain to the internal structure of the mountain tract. Here we must first take note of the coast line. The coastal slope of California characteristically rises abruptly from sea level to elevations of from 2,000 to 5,000 feet within a short distance from shore, from Cape Mendocino to Point Conception, with certain notable breaks in its continuity which are susceptible of special explanation. If along the shore line at the base of this abrupt slope we draw straight lines which are tangent to the headlands or chords to the minor embayments of the coast, these lines fall into two fairly constant orientations and clearly bring out the fact that the shore line has in reality a zigzag course, due apparently to the alternate control of two systems of structural lines, one of which is between N. 37° W. and N. 40° W., and the other between N. 10° W. and N. 15° W., thus intersecting at an angle of about 26°. Under this scheme of discrimination of the orientation of different portions of the coast line, the bearings of the following divisions may be thus listed:

LOCALITIES.	BEARING OF MEAN LINE.	DISTANCE IN GEOGRAPHICAL MILES.
Cape Mendocino to Punta Gorda	N. 12° W.	14
Punta Gorda to Shelter Cove	N. 40° W.	25
Shelter Cove to Point Arena	N. 10° W.	64
Point Arena to Golden Gate, thru Tomales Bay	N. 40° W.	90
Golden Gate to Pigeon Point	N. 15° W.	40
Pigeon Point toward Santa Cruz	N. 40° W.	21
Point Pinos to Point Sur	N. 13° W.	19
Point Sur to Port Hartford	N. 37° W.	89
Port Hartford to Point Conception	N. 6° W.	44

Now it is difficult to regard any considerable portion of the abrupt coastal slope of California between Cape Mendocino and Point Conception as other than a more or less degraded fault-scarp. If this view be accepted, it is clear that the trend of the coast and its geomorphic profile have been determined by two systems of faults meeting or intersecting at an angle of about 26° on their strike. Making some allowance for cliff recession, the base of both systems of scarps must lie some little distance off shore and be buried by the notable embankment of littoral sediments which conceals the true profile of the submarine rock surface.

Of the two systems of faults thus recognized as controlling the trend of the coast, one, viz. that which bears N. 37° W. to N. 40° W., conforms, as will be shown later, more or less closely with the prevailing structural lines, such as faults, folds, and belts of igneous rock found in the Coast Ranges; while the more meridional system is not a prominent feature of the Coast Ranges. It follows that since the mean trend of the California coast lies between the bearings of the two fault systems, the tectonic lines of the Coast System, if followed northwesterly, eventually emerge upon the coast. This obliquity of the

tectonic lines of the Coast System to the general trend of the coast has long been familiar to California geologists and has been particularly noted by Fairbanks,[1] but the probable explanation of it has not heretofore been set forth.

The coastal scarp is interrupted at a number of points and in a variety of ways. The most notable and interesting interruption is that of the Bay of Monterey. This is not only an embayment of the coast, but is a depression in the Coast Ranges extending down over their submarine portion to the 12,000-foot contour below sea-level. It brings the 3,000-foot submarine contour well inside the general line of the coast. This submarine valley has been regarded by some writers as a submerged valley of subaerial erosion, but there is little warrant for this view and much that conflicts with it. The valley of the Bay of Monterey, subaerial and submarine, is a synclinal trough the axis of which is approximately normal to the trend of the coast and of the Coast Ranges as a belt. In the axis of the syncline, and probably parallel to it, is a fault seen in the canyon between Pajaro and Chittenden, which brings down the Tertiary rocks on the north side against the pre-Cretaceous granitic rocks of the Gavilan Range. Another interruption of the continuity of the coastal scarp is at the Golden Gate. Here the Coast Ranges have been locally deprest and the land valleys which were formerly drained by a trunk stream, where the Golden Gate now is, have been flooded by the waters of the ocean. The axis of this depression is, however, not well known. A third, apparent rather than real, interruption of the coastal scarp occurs at the place where the Point Reyes Peninsula projects out beyond the general line of the coast. Inside of the peninsula, however, there is a long narrow valley, the northern end of which is occupied by Tomales Bay and the southern end by Bolinas Lagoon, which separates it from the mainland proper; and to the east of this valley the coastal scarp rises with exceptional boldness.

The coastal scarp has had its profile modified in many places by wave-cut terraces formed during the uplift of the coast by stages in Pleistocene time, as previously stated. The relation of the coastal scarp to deformed basins of Merced (late Pliocene) strata indicate that it originated, in its essential features, at the period of orogenic activity which brought the Tertiary to a close. South of Point Conception the twofold system of faults which determines the configuration of the coast gives out and we enter upon a region of probably more complicated structure. The Santa Barbara channel appears to lie in a geosynclinal trough between the Santa Ynez range and the island chain from Anacapa to San Miguel. On the northeast side of San Clemente is a sharply defined fault-scarp, indicating that the island is a portion of an uplifted and tilted orographic block. The fault along which the scarp has been formed probably extends as far as the east side of Santa Barbara Island. San Clemente Island presents a magnificent series of wave-cut terraces up to an elevation of 1,500 feet. San Pedro Head is similarly uplifted and terraced, while the intervening island, Santa Catalina, shows no evidence of corresponding uplift, but has on the contrary been deprest. On the whole, the channel island platform between the edge of the subcontinental shelf and the coast presents the characters of a sunken mountainous tract, the inequalities of the surface of which are partly due to acute deformation and partly to erosional sculpture when the region was above sea-level. A more detailed interpretation of the structure of this region is rendered difficult by the absence of adequate soundings of the sea-bottom.

Granitic Rocks. — Coming now to the consideration of the more important structural features of the Coast System, in the territory between the coast and its eastern margin, it must be stated that even here our information is very scant. One of the most important features of the Coast System from a structural point of view is the occurrence of a belt of granitic rock having a very notable linear extent thruout the ranges. This granite, as has been already stated, appears, in the vicinity of Tejon Pass, both from

[1] Am. Geologist, Vol. XI, Feb. 1893, p. 70.

its character and from the continuity of its exposure, to be identical with the granite of the Sierra Nevada. To the south of the Mojave Desert, it is very extensively and boldly exposed in the San Gabriel and San Bernardino Ranges and in other portions of the Coast System, as far south as the Mexican boundary. It also has broad exposures in the comparatively low-lying desert floors of Southern California, as shown by Hershey,[1] and in the Perris plain.

To the northwest of Tejon Pass, this granite appears in a series of linearly disposed areas extending thru the ranges. It forms a notable feature of the Santa Lucia Range on the west of the Salinas Valley, and also of the Gavilan Range to the east of the same valley. The granite of the Santa Lucia Range runs out to sea at Point Pinos near Monterey, while that of the Gavilan Range extends into Santa Cruz County and appears on the coast at Point San Pedro, a few miles south of San Francisco. Farther north it is seen in the Farallon Islands, the Point Reyes Peninsula, and on Bodega Head. The Santa Lucia and the Gavilan thus expose two quite distinct lines of granitic outcrop, practically parallel, and both crossing the general trend of the Coast Ranges obliquely and reaching the coast. Indeed, the easterly limit of all the granite of the Coast Ranges crosses the entire breadth of the latter obliquely between the Tejon Pass and Bodega Head. This signifies, of course, that whatever manifestations of crustal deformation elevated these belts of granite, the lines or axes of such deformation were not coincident in direction with the mean trend of the Coast Ranges, or with the mean trend of either of the margins of the Coast Ranges. It is noteworthy, too, that all of the Coast Range granite as far south as the vicinity of Tejon Pass lies to the southwest of the Rift along which the movement occurred which generated the earthquake of April 18, 1906. It is further noteworthy that near the northern end of the granite belt at Tomales Bay and Bodega Head, the Rift actually follows the line of contact between the granite on the west and the sedimentary rocks which are faulted against it. These facts suggest that very probably the Rift is similarly situated in the more southern Coast Ranges with reference to a deeper-seated contact between granite and sedimentaries; in other words, that the eastern edge of the Coast Range batholith, whether that edge be an original feature of the batholith or a feature determined by faulting, is with some degree of probability the line which determines in part the course of the modern Rift. Southward from the vicinity of Tejon Pass, however, the Rift passes into the granitic terrane.

Folds. — The pre-Knoxville folds of the Coast Ranges are little known, owing partly to the burial of the Franciscan rocks by later deposits, and partly to the complexity of the structures where the rocks are exposed and the difficulty of discriminating the effects of the earlier and the later movements; but chiefly owing to the absence of adequate topographic maps, so necessary for such studies. The conspicuous folds of the Coast Ranges are those which have been imprest upon the Tertiary and older strata together. These are usually rather sharp and more or less symmetrical synclines and anticlines, involving usually many thousands of feet of strata. In some cases these are asymmetric and even overturned, as in the Mount Diablo region, but they are never so closely apprest as to induce general and important deformation of the internal structure of the rocks affected. The folding has been effected without flowage, except perhaps locally where soft clays or shales were involved, and there has been no development of slaty cleavage or schistosity. In general the axes of the folds have a northwest-southeast trend, but there are numerous deviations from this rule and the axes of the minor folds are usually more or less divergent, as is of course generally true. There is, however, a pronounced parallelism in the dominant synclines and anticlines, the axes of which extend for many miles. Several of these are more or less oblique to the mean trend of the Coast Range belt, and thus appear to be truncated on the coast line, or on the eastern margin of

[1] Bull. Dept. Geol. Univ. Cal., vol. 3, No. 1.

the ranges. The coincidence o y of the larger valleys with a synclinal axis is very marked.

Faults. — In the Coast Ranges there are numerous faults, but our knowledge of them is limited, owing to the small amount of geological mapping which has been done in the region. With the extension of cartographic work, many more than are now known will doubtless come to light. Of those at present known, the great majority have a general northwest-southeast strike, but there are several minor faults which trend transverse to the general strike. The faults of the Coast Ranges, as well as those of other parts of California, are indicated, as to position and extent, on Map No. 1. A summary reference to them is all that will be here attempted.

The most northerly fault of the Coast Ranges is one which Mr. O. H. Hershey calls Redwood Mountain fault. It is an overthrust, according to Mr. Hershey, heading to the northeast and having a throw of probably over 5,000 feet. It trends southeast along the southwest flank of South Fork Mountain for scores of miles, and doubtless determines the very straight trend of this great ridge. Parallel to it, on the southwest side of Redwood Creek, near Acorn, there is another fault having a throw of at least 1,000 feet, according to Mr. Hershey. Its extent is unknown. The precipitous southwest front of Mount St. Helena has been shown by Osmont [1] to be a degraded fault-scarp; and the downthrow on the southwest side of the fault is estimated by him to be not less than 2,500 feet. The western edge of the Sacramento Valley, from Benicia to Cordelia, is probably determined by a fault with an easterly downthrow.

In the Mount Diablo region, there is a pronounced overthrust fold which causes Miocene strata to rest upon Pliocene strata with a dip of 30° to 45° to the northeast. Louderback's work on the structure of Mount Diablo has shown that this over-tipt fold passes into a thrust fault whereby a considerable proportion of the mountain has been shoved to the southwest.[2] The west side of San Ramon and Livermore Valleys is bounded for the most part by a steep mountain wall at the base of which, near Pleasanton, the Tertiary rocks are faulted down against the Franciscan. This fault extends southward thru Calaveras Valley and past Mount Hamilton. Its general course is about N. 35° W. It has an extent of at least 60 miles and may be very much longer. In the Berkeley Hills to the east of this there are many minor faults, both overthrust and normal, which will not be described in detail. In the Mount Hamilton Range, between the crest and the Santa Clara Valley, there are several faults, notably the Mission Creek, Mission Peak, Mount Hamilton, and Master's Hill faults, which have a more or less regular northwest-southeast trend; and there are several shorter faults transverse to these, and of variable strike.

The valley of the Bay of San Francisco and its prolongation southward in the Santa Clara Valley is bounded on the northeast side by a range of hills which presents a very even, straight, and on the whole, but little dissected, front to the southwest. This even front extends from near Point Pinole, on San Pablo Bay, to the vicinity of Hollister, a distance of about 100 miles, forming a very striking geomorphic feature of the Coast Ranges. At Berkeley and Oakland, and southeast of the latter, there is evidence that this even front represents a somewhat degraded fault-scarp, or series of scarps, and this interpretation may with very probable truth be placed upon it for its entire extent. Near Berkeley the slope of this degraded scarp is traversed by supplementary step faults, which are not improbably characteristic of it in other places; so that in regarding the feature as a fault-scarp it is not intended to apply that term too narrowly, but to include rather the idea of a zone of acute deformation traversed by step faults. This line has a course of about N. 35° W. North of San Pablo Bay, on the geographic prolongation of the line, a similar feature, tho by no means so straight, is found on the east side of the

[1] Bull. Dept. Geol., Univ. Cal., vol. 4, No. 3, p. 78.

[2] Results not yet published.

Santa Rosa and Russian River Valleys up to about Cloverdale. Here, however, evidence of faulting is lacking, altho it is known in places to be a line of flexure. Along the base of this line of scarp, between Oakland and San Jose, occurred the fault which caused the earthquake of 1868. It may be referred to as the Haywards fault, from the fact that it passes thru that town.

An interesting and important fault traverses the peninsula of San Francisco, a little south of the city. The course of this fault can not be precisely determined, as its trace at the surface is obscured by Pleistocene and recent deposits. Its approximate position is at the southwest base of San Bruno Mountain, with a strike of about N. 43° W. By this fault the Merced strata, which are well exposed on the sea-cliffs south of Lake Merced to the thickness of over a mile, are dropt down against the Franciscan rocks, the throw being estimated at not less than 7,000 feet. To the northeast of the main fault, and close to the face of the mountain, is an auxiliary fault, and between these two faults there is a block of the Franciscan which has dropt only to a limited extent, and which is of the same character as the kernbuts of the Kern River.[1] The bold and precipitous southwest face of San Bruno Mountain is thus a fault-scarp with two facets, one for the main fault and the other for the auxiliary, both being well exprest in the geomorphic profile of the mountain. This fault-scarp appears to be the southern prolongation of the scarp which forms the coastal steep slope to the north of the Golden Gate, and seems to converge upon the San Andreas fault, off the Golden Gate, making a very acute angle with it. It affords an excellent illustration of the general fact above alluded to, that the northwesterly members of the fault system controlling the configuration of the coast are prolongations of fault-lines within the Coast Ranges. Knowledge of the extent of this fault, altho its throw is so notable, is limited to the peninsula of San Francisco.

Outside of Fort Point, at the Golden Gate, and a little south of the point, is a very well exposed fault which appears to strike southeast across the city of San Francisco. The fault is nearly vertical and has a throw of at least some hundreds of feet, whereby the serpentine on the north has been dropt against a formation of radiolarian cherts.

The most interesting fault traversing the Peninsula of San Francisco is the San Andreas fault, on which movement was renewed on April 18, 1906, causing the earthquake. The extent and course of this fault are described in detail elsewhere. To the southwest of the San Andreas fault, on the Peninsula of San Francisco, and in the Santa Cruz Mountains, are several other faults of notable extent. Of these may be mentioned the Fifield, Pilarcitos, Castle Ridge, Butano, Boulder Creek, and San Gregorio faults, all of which are important features of the structure of the region.

On the southwest side of Montara Mountain is a very precipitous seaward slope, at the base of which strata of Miocene age are tilted at rather abrupt angles against the granite. The strata of arkose sandstone at the base still rest against the original floor of deposition, but it is difficult to see how such an acute uplift could take place in a granite *massif* without deformation of the granite. Such deformation might take the form of plastic flow if it were sufficiently deep-seated, or it might find its expression in a zone of faults; and as there is no evidence of plastic deformation, it is concluded that the uplift of Montara Mountain was effected by faulting within the granite, the same deformation appearing as flexure in the stratified rocks which flank the mountain on this side.

Northeast of the San Andreas fault are the Belmont and Black Mountain faults, the latter a branch from the San Andreas fault. In the gap between the Santa Cruz and Gavilan Ranges is a fault followed by the canyon of Pajaro River near Chittenden, which drops the Tertiary formations on the north against the pre-Franciscan granitic rocks of

[1] Bull. Dept. Geol., Univ. Cal., vol. 3, No. 15.

the Gavilan Range on the south. This fault is interesting for several reasons: it lies approximately in the axis of the geosyncline of the Bay of Monterey; it is transverse to the San Andreas Rift and intersects it; and it is near the place where the surface rupture of the San Andreas fault ceased on April 18, 1906.

South of the Bay of Monterey, one of the dominant structural lines of the Coast Ranges is the Santa Lucia fault, at the base of the Santa Lucia Range on the border of Salinas Valley. It is traceable from the vicinity of Bradley to the Bay of Monterey and it is probably the chief factor in determining the course of the Salinas-Valley and the steep easterly front of the Santa Lucia Range. Near its southern end, the Santa Lucia fault is paralleled on the southwest by another fault which probably determined to some extent the course of the valley of San Antonio River. Farther south a fault parallels the last two, between Dove and Templeton; and to the southwest of this lies the much longer fault which passes close to San Luis Obispo, extending from near San Simeon to the drainage of the Santa Ynez.

The northeastern flank of the San Emidio Range, at the southern end of the great valley, is with little question a fault-scarp. The same may be said of the north flank of the Santa Ynez Range and the south flank of the Santa Monica Range. The San Gabriel fault, which bounds the range of that name on the south, branches from the San Andreas fault near San Bernardino and follows the base of the range with an east-west trend. Beyond Pasadena it bends slightly to the north and extends thru to the coast in the vicinity of Carpenteria. Near Pasadena a branch fault leaves it, with a northwesterly strike, on the northeast side of the Verdugo Mountains. Southeast of Los Angeles, the most notable faults are the San Jacinto and Elsinore faults, both of which have very pronounced scarps. There are, however, several others. All the faults in this region have a northwest-southeast strike, and are thus in contrast to the system of faults extending from Point Conception to the Colorado Desert along the Sierra Madre, in which the dominant trend is east and west.

The foregoing summary enumeration of the more important faults at present known in the Coast System of mountains makes it clear that the San Andreas fault, upon which movement took place on April 18, 1906, is not a singular or unique feature of the structure of these mountains. It is only one of many faults, on all of which in time past there have occurred many differential movements, each productive of an earthquake. Map No. 1, upon which the above faults are represented, indicates other faults in California, Nevada and Oregon at present known to geologists.[1] Perhaps the most interesting of these, from the present point of view, is the fault at the eastern base of the Sierra Nevada, upon a portion of which the movement took place that caused the earthquake of 1872. The map may be regarded as a preliminary attempt to bring together, in cartographic form, our knowledge of the position of faults in this region. A full discussion of these features, with references to the literature bearing upon them, would be out of place here, altho their occurrence suggests seismic possibilities.

GEOMORPHIC FEATURES.

Certain of the geomorphic features of the Coast Ranges, particularly as regards their margins, have necessarily been alluded to in the discussion of the structure. It is proposed here to describe quite briefly the salient characters of the relief, in their relation to the structure.

The Coast Ranges in general, between the coast and the Great Valley and north of Santa Barbara Channel, comprize a series of ridges and intervening valleys of mature aspect.

[1] In compiling the data for the representation of the faults of California, free use has been made of information kindly supplied by Messrs. H. W. Turner, W. Lindgren, W. C. Mendenhall, H. W. Fairbanks, J. S. Diller, F. M. Anderson, R. Arnold, J. C. Branner, G. D. Louderback, and O. H. Hershey.

The ridges exhibit for the most part a pronounced parallelism in a direction more or less oblique to the mean trend of the coast and of the Coast Ranges as a belt. The highest of these ridges rarely exceed 5,000 feet in altitude and their crests usually range between 2,000 and 4,000 feet above sea-level. Rarely the tops of the ridges are more or less flat, presenting the character of a rolling upland, the rule being that the crests are determined by the intersection of the valley slopes on either side. In the northern Coast Ranges, however, it is generally true that the ridge crests over wide areas reach about the same altitude and give the observer the impression of a dissected upland of fairly uniform and gentle slope. The valleys in which the streams flow are usually wide-bottomed in the softer formations and narrow in the harder rocks. In such portions of the region as have been geologically examined, it appears clear that the courses of these streams are closely, tho of course not wholly, controlled by the strike of the rocks or the strike of faults. The general scheme of drainage is that which might be termed subsequent, the streams having adjusted themselves to the structural lines, and having been greatly extended by headwater erosion along those lines at the expense of original consequent streams, traversing the region transversely to the trend of the structure to the sea on the one side, and to the Great Valley on the other. This interpretation is rendered more plausible by the fact that, in a general way, the broad structure of the Coast Ranges appears to be that of a geanticline, with various subordinate folds, the dissection of which by erosion reveals the Franciscan rocks in the central portion of the ranges, flanked on either side by rocks of later age. This interpretation appears to be quite acceptable for the Eel River and its various branches, which constitute the chief drainage of the northern end of the region. This drainage has all the characters of a subsequent system, and is in harmony with the mature aspect of the ridges and valley slopes. All the numerous tributaries of the river flow in longitudinal valleys, parallel or subparallel to one another, and connected by short transverse streams cutting thru the intervening ridges; and the course of the longitudinal valleys is that of the strike of the rocks, being, like the latter, oblique to general trend of the Coast Range belt. Thruout this region, within the hydrographic basin of the Eel River, there are below the crests of the ridges numerous instances of high valleys and broad, more or less obscure terraces, representing an inheritance from earlier stages of the geomorphic evolution of the region, when it stood at lower levels than at present. These have been described in a valuable paper by Diller.[1]

Between the headwaters of Eel River and the Bay of San Francisco the interpretation of the drainage as subsequent is not so certain, altho here the general geomorphic profile is even more mature than it is on the north, a fact referable to the softer character of certain geological formations which prevail. Here we have, as before, a system of stream valleys, notably Russian River Valley, Sonoma Valley, Napa Valley, and Berryessa, and Clear Lake Valleys, which are clearly evolved by stream erosion under the control of structure. The transverse connecting link from one longitudinal valley to another, which is so characteristic of subsequent drainage, is not apparent on the maps, but its absence may be more apparent than real. The lower stretch of Russian River, from Healdsburg to the sea, has the appearance of a transverse stream tapping a longitudinal valley of very mature character, and may be the remnant of an original consequent stream. This view, however, is open to the objection that the lower stretch of Russian River near the sea has a more youthful aspect than might reasonably be expected under the hypothesis. On account of the rather immature character of the transverse outlet of Russian River, it has been suggested that it is of later date than Russian River and represents a small stream which has cut its way back from the coast and captured the waters of the river, which formerly went to the Bay of San Francisco, the capture being

[1] U. S. G. S. Bulletin, 196.

facilitated by the deformation of the region. The offsetting consideration to this objection, based on the less mature aspect of this part of the valley, is that it traverses much harder rocks than are found in the wider valley above. In a word, the view that the lower transverse stretch of Russian River may be the remnant of an original consequent stream, from which, by subsequent development, has been evolved the longitudinal Russian River Valley, has not yet been satisfactorily negatived.

Somewhat similar features occur on the east side of the Coast Ranges. Cache Creek and Putah Creek, draining longitudinal valleys within the Coast Ranges, both emerge upon the Great Valley thru transverse gorges in the Blue Ridge, the most easterly of the Coast Ranges. These transverse gorges can scarcely be regarded as other than consequent trunks crossing a hard barrier within which, in softer formations, longitudinal or subsequent valleys have been evolved. The apparent absence of the transverse connecting links between Napa, Sonoma, and Petaluma Valleys is explained when it is recalled that while the streams draining these valleys flow directly to salt water, they nevertheless flow to a drowned valley. The trunk stream trench from which Petaluma, Sonoma, and Napa Creeks are subsequent branches lies below the waters of San Pablo Bay. In general, Santa Rosa Valley (lower part of Russian River Valley), Petaluma Valley, Sonoma Valley, and Napa Valley have been evolved by erosion along synclinal axes. This fact also tends to weaken their interpretation as due to subsequent development by headwater erosion; since, if the synclinal folds were exprest as troughs at the surface at the time of the folding, then the drainage would have been both consequent and parallel to the structure.

Coming farther south, the valley of the Bay of San Francisco and its extension in the Santa Clara Valley is a large feature in which deformation and erosion have probably played equal rôles. Its trend is strictly determined by the Haywards fault line previously described. Southward from Hollister, the valley loses its breadth and passes into the much more constricted valley of the San Benito River, draining the Coast Ranges to the east of the Gavilan Range. The Bay itself and its inland extensions afford a magnificent illustration of a drowned valley-land due to subsidence of the valley-bottoms below sea-level.

Livermore Valley, a few miles to the east of the Bay of San Francisco and separated from it by the ridge of the Berkeley Hills, is a very noteworthy feature. It is a broadly expansive alluviated valley, bounded on the west by the degraded fault-scarp which limits the Berkeley Hills to the east; on the east by the slopes of Mount Diablo; and on the south by the slopes of Mount Hamilton. On the north it is open by way of the wide and low San Ramon Valley to Suisun Bay, and the northern portion of the valley drains this way. The greater part of the waters which come to it from Mount Diablo and from Mount Hamilton, however, are carried off by Alameda Creek thru Niles Canyon, a narrow gorge which transects the bold ridge separating it from the Bay of San Francisco. Alameda Creek has a hydrographic basin of 600 square miles, and it is a remarkable fact that it finds its outlet across the strike of the range thru a bold ridge, instead of following the wide open valley leading directly to Suisun Bay with no barrier in its path. It is a fair inference that Livermore Valley is structural rather than erosional in its origin and that, anterior to the acute deformation of the region, the drainage was consequent in the path followed by Niles Canyon. The deformation involved the uplift of the Berkeley Hills and the complementary depression of the Livermore Valley tract, and this deformation proceeded at a rate which was sufficiently slow to permit the stream, by downward corrasion across the rising mass, to maintain its course. Alameda Creek in Niles Canyon is thus a remnant of the consequent drainage of the region and is antecedent to the uplift which gave rise to the Berkeley Hills.

In the Coast Ranges between the Bay of Monterey and the Santa Barbara Channel, the chief valleys are those of Salinas River and its tributary, the San Juan; the Carissa Valley, and the valleys of the Cuyama and Santa Ynez Rivers. Of these the Salinas Valley is the largest. It is a wide, terraced valley cut by the river out of rather soft Tertiary and later deposits, which appear to have been in part let down against the older rocks of the Santa Lucia Range by the Santa Lucia fault. In its lower part it lies between the Gavilan and Santa Lucia Ranges, and the trend thus established is maintained by the main stream as far as San Miguel. Beyond that the same general trend is continued up its tributary, the San Juan, and thence thru the Carissa Plains to a point close to the southern end of the Great Valley. The eastern side of the upper end of the valley, particularly the eastern side of the Carissa Plains, follows closely the line of the modern earthquake rift to be presently described; and there can be little doubt, not only that in so far as the valley is an erosional feature its erosion has been controlled by structural features, but also that deformational processes have had a considerable share in its evolution. The axis of the valley thus indicated is singularly straight and has a length of about 175 miles. Its upper part, the Carissa Plains, is an arid plain without drainage and contains a very saline lake. This plain is a surface of alluviation. The lower end of the valley opens widely on the Bay of Monterey and the fine stream terraces which flank its sides afford an excellent record of the recent uplift of the region.

The valley affords another striking illustration of the obliquity of the geomorphic as well as the structural features to the general trend of the Coast Range belt, and their constant tendency to emerge upon the coast. From the eastern margin of the valley at the south end of the Carissa Plains, one can look down upon the Great Valley, near Sunset, a few miles distant; and only a narrow ridge separates the two valleys, altho they differ greatly in altitude. From this point in its course of 175 miles, Salinas Valley crosses the entire width of the Coast Ranges. South of San Miguel, the Salinas River proper lies in a less open valley with north and south trend as far as Templeton, a distance of about 15 miles, and then opens out into a wider valley having a northwest-southeast trend for about 35 miles to the headwaters of the stream. Several of the minor tributaries of the Salinas show a marked tendency to the development of subsequent valleys. On the east side of the river, this is particularly marked on San Lorenzo Creek in Priest Valley, and on Chalome Creek in Chalome Valley. These comparatively large valleys may be referable in part, however, to deformation, inasmuch as they are on the line of the Rift. Their geomorphic history has not yet been studied. On the west side of Salinas Valley the two chief tributaries, the San Antonio and the Nacimiento, have developed well-defined subsequent valleys in the heart of the Santa Lucia Range.

In the valley of the Cuyama or Santa Maria River, the effect of a twofold structural control is apparent. The upper reaches of the river flow thru a broad valley with an alluviated bottom on the northeast side of the San Rafael Range. The general trend of the river in this part of its course is northwest-southeast, and it is separated from the Carissa Plains by a high mountain ridge with a very precipitous southwest front, which probably represents a fault-scarp. Below this expansive high valley, the stream enters a rather narrow canyon and shortly after this bends at right angles and flows southwest toward the coast, entering eventually on the broad Santa Maria Valley which is open to the sea. The contrast in the geomorphic character of the upper and lower reaches of the river, the greater age of the former, and the sudden change in the course of the stream where the two types of geomorphy meet, suggests that the high valley of the upper reaches was once connected with the Salinas drainage and that it has been captured from the latter, in comparatively recent time, by a stream cutting back from the coast at the northwest end of the San Rafael Range.

In the valley of the Santa Ynez, there is a marked departure from the northwest-southeast trend which characterizes the geomorphic features of the Coast Ranges in general, and a more striking instance than any yet cited of the obliquity of those features to the general trend of the Coast Range belt. The valley lies nearly east and west and its general slope is southward to the base of the precipitous northern face of the Santa Ynez Range. This face is, as has been indicated, a fault-scarp; and the course of the valley is thus seen to be in intimate relation to this dominant structural feature. To the west the valley opens widely to the sea, while to the east it loses its individuality in the headwater canyons of eastern Santa Barbara County and western Ventura County.

Between the Santa Ynez Valley and the upper Cuyama is the rugged and deeply dissected country culminating in the San Rafael Mountains on the northern side of the tract. This mountainous belt has a trend intermediate between the pronounced east-west trend of the Santa Ynez Range and the northwest-southeast trend of the Coast Range ridges and valleys to the north. For a portion of its length the belt is bounded on the south by the Santa Clara Valley, with a general east and west course; but across the headwaters of Santa Clara River the mountainous tract persists and finds its prolongation, with the same general trend, in the San Gabriel Range, and beyond Cajon Pass in the San Bernardino Range, both bold and lofty sierra. It may even be considered as extending, under the name of the Chocolate Mountains, to the Colorado River above Yuma. From Tejon Pass southeast to Cajon Pass, the northern side of this mountain tract presents a very abrupt front with a very straight course. At the base of the abrupt slope lies the San Andreas Rift. To the north of this, and between it and the southeast scarp of the southern Sierra Nevada, lies the Mojave Desert. To the south of the southeast end of the San Bernardino Range and west of the Chocolate Mountains lies the Colorado Desert. As has been already indicated, the south side of the San Gabriel Range is determined by a profound fault. Lying thus between two faults, the range is a magnificent example of a horst which has been thrust up between its bounding faults. It is the convergence of these two bounding faults which segregates the San Gabriel Range from the San Bernardino Range in the vicinity of Cajon Pass. The latter range is similarly bounded on the south by the same fault as that which determines the south front of the San Gabriel Range, but here it is coincident with the Rift. Between Los Angeles and Ventura lie the short ranges known as the Santa Monica and the Santa Susannah Mountains, inclosing San Fernando Valley. The Santa Monica Range is probably on the same line of orogenic uplift which finds its expression farther west in the Santa Cruz and Santa Rosa Islands.

South of the San Gabriel Range lies the fruitful valley of southern California, extending with an east-west course from the sea to San Bernardino. South of this valley, and between the Colorado Desert and a somewhat elevated coastal plain bordering the Pacific, is a mountainous tract, the ridges of which swing around into a more northwest-southeast trend, and so conform again with the prevailing trend of the ridges and valleys of the Coast Ranges north of the San Rafael Mountains. The valleys in this region are, however, less regular in their orientation than those of the northerly Coast Ranges, and the geomorphic features are less mature, if we except certain very old features which have survived from an earlier cycle of geomorphic evolution. The consequent character of the streams on the seaward slope is much more pronounced than in any part of the northern Coast Ranges, and on the whole the geomorphy of the region must be regarded as less advanced than to the northward, and more closely allied in its morphogeny with the Sierra Nevada than with that of the Coast Ranges of northern California.

The notable ranges of this region are the Santa Ana Mountains and the San Jacinto Mountains. The former present the features of a seaward sloping, tilted, orographic

block, with a very straight and abrupt fault-scarp facing the northeast and overlooking the Perris Plain. This is an elevated, and as yet little dissected, peneplain with remnants of Tertiary or later deposits resting upon it, indicating that it has, in part at least, but recently been resurrected from a buried condition. In San Diego County the Santa Ana Mountains find their prolongation in a less regular and broader group of ridges, but doubtless the same tilted block structure prevails to the international boundary and beyond, since the northeast scarp appears to persist in the same general trend, and the same type of consequent drainage characterizes the seaward slope. Still east of the line of the scarp in southern San Diego County, there is another orographic block, bounded on the east by a very recent and very precipitous scarp looking out over the desert.[1] To the northwest the range becomes subdued in the Puente Hills, where a broad anticlinal structure replaces in part the deformation by faulting. In two notable instances, and perhaps in others, the seaward streams of the Santa Ana Mountains cut entirely thru the range and drain the valley-land beyond its northeasterly scarp. These are the Santa Ana and the Santa Margarita Rivers. They are both probably antecedent to the more acute phases of the tilting of the region and have persisted in their course during the development of the fault-scarp.

The San Jacinto Mountains form an important feature of the region as a bold ridge with northwest-southeast trend lying between Perris Plain and the northern end of the Colorado Desert. Both sides of the range are precipitous and are probably determined by faults. On the southwest side there were notable ruptures of the ground in the earthquake of 1898, indicating that the fault on that side is still in active development.

---

[1] Verbal communication from Dr. H. W. Fairbanks.

THE SAN ANDREAS RIFT AS A GEOMORPHIC FEATURE.

GENERAL.

Extending thru the greater part of the Coast System of mountains from Humboldt County to the Colorado Desert, a distance of over 600 miles, is a line or narrow zone characterized by peculiar geomorphic features, referable either directly to the modern deformation of the surface of the ground or to erosion controlled by the lines upon which such déformation has taken place. This peculiar feature has been known, both to Californian geologists and to residents of the sections where its characters are most prominent, but its extent and importance were not fully appreciated until after the earthquake of April 18, 1906. It is commonly reported among the residents of the southern interior Coast Ranges, particularly in San Benito, Monterey, and San Luis Obispo Counties, that displacement of the ground occurred on this line in the earthquake of 1857 and in certain later earthquakes. The first reference in scientific literature to this feature appears to have been in the year 1893, in a paper entitled "The Post-Pliocene Diastrophism of the Coast of Southern California," by Andrew C. Lawson, which is quoted in the sequel. The next reference to this peculiar line is in the eighteenth annual report of the U. S. Geological Survey for 1896–1897, Part IV, in a paper by Schuyler on "Reservoirs for Irrigation," where, pp. 711–713, the significance of the line is fully recognized in the following words quoted in full:

> This reservoir has especial interest, not only as the first one of any magnitude completed on the Mojave Desert or Antelope Valley side of the Sierra Madre in southern California, but because it lies directly in the line of what is known as "the great earthquake crack" of this region, which is marked by a series of similar basins behind a distinct ridge that appears to have been the result of the great seismic disturbance.
>
> This remarkable line of fracture can be traced for nearly 200 miles thru San Bernardino, Los Angeles, Kern, and San Luis Obispo Counties, and deviates but slightly here and there from a direct course of about N. 60° to 65° W. There appears to have been a distinct "fault" along the line, the portion lying south of the line having sunken and that to the north of it being raised in a well-defined ridge. In many places along the great crack, ponds and springs make their appearance, and water can be had in wells at little depth anywhere on the south side of the ridge before mentioned. A tough, plastic, blue clay distinguishes the line of the break, in this portion of its course at least; and where the line crosses Little Rock Creek, the blue clay has formed a submerged dam, which has forced the underflow near the surface and created a "cienega" immediately above it. After crossing the line, the water of the creek drops quickly away into the deep gravel and sand of the wash. The same effect is noticeable at other streams, and it has been suggested as the probable cause of the very distinct rim marking the lower margin of the San Bernardino Valley artesian basin and confining its waters within well-defined limits, as this rim is nearly on a prolongation of the line that is traceable on the north side of the mountains — the break having crost the mountains thru the Cajon Pass on the line of Swartout Canyon.

In 1899 the essential features of the same line in the region north of the Golden Gate were recognized and discust by F. M. Anderson.[1] In later years Dr. H. W. Fairbanks has traced out the line in various field trips and has given several public lectures descriptive of its features and its significance, but has published no systematic account of his studies.

The fact that the earthquake of April 18, 1906, was caused by a rupture and displacement of the earth's crust along this line for a distance of about 190 miles, immediately focussed the attention of local geologists upon it. Among those engaged upon

[1] The Geology of the Point Reyes Peninsula, Bull. Dept. Geol., Univ. Cal., vol. 2, No. 5, p. 143 *et seq.* Anderson, however, supposed, as is indicated by the last paragraph of his paper, that the faulting antedates entirely the Pleistocene terrace formations.

its investigation, it became known as the "rift line." Since the earthquake it has been traced as a geomorphic or physiographic feature from Humboldt County to the Colorado Desert, with a possible gap between Shelter Cove and Point Arena, where, if continuous, it lies beneath the Pacific. Its continuity has, however, been satisfactorily established from Point Arena to Whitewater Canyon, at the northern end of the Colorado Desert, a distance of 530 miles. Thruout this entire distance it lies along depressions or at the base of steep slopes which are either the direct result of crustal displacement or of stream erosion, operating with exceptional facility along lines of displacement. There can be no doubt that the displacements have been recurrent thru a considerable part, if not the whole of Pleistocene time, and that in parts of its extent, at least, the movements have taken place on fault-lines which originated in pre-Miocene time. The later movements on this line have given rise to minor features which subaerial and stream erosion have not yet obliterated, and it is these minor features chiefly which have attracted attention to the Rift by reason of their striking contrast with more common geomorphic forms due to erosion. These minor features are chiefly low scarps and troughs bounded on one or both sides by low, abrupt ridges in which frequently lie ponds or swamps of quite small extent.

A summary account will now be given of this rift line as a geomorphic feature.

HUMBOLDT COUNTY.

The most northerly point in California at which geomorphic features directly referable to the violent rupture of the earth's crust have been observed are those noted by Mr. F. E. Matthes in the vicinity of Petrolia in Humboldt County. Here south of Petrolia, on high bare mountain spurs between Cooskie, Randall, and Spanish Creeks, he reports the occurrence of several small ponds and ridges such as have been familiar to those engaged in the field study of the earthquake phenomena as characteristic Rift features. Similar features are also found at the base of these spurs near the shore. These are in line with similar features found by the same observer between Telegraph Hill and Shelter Cove, a few miles to the southeast. Here, particularly in Wood Gulch (plate 1), is a narrow depression with ponds, ridges, and saddles, which appears to be essentially a feature due to deformation and to have determined the course of the drainage. The course of the depression is about N. 25° W. In this depression lies the trace of the fault upon which movement took place on April 18, 1906. Its course, if followed southward to the cliffs above Shelter Cove (plates 2A, 3A, B), heads out to sea with a trend nearly parallel to the coast. Great landslides occur along the coast in proximity to this line, and are in part on the Rift. The rocks traversed by the Rift in this part of Humboldt County appear to consist wholly of shales, sandstones, and conglomerates which are probably of Cretaceous age, altho since the geology of the region has not been studied, positive statements in this regard can not be made. The region is high and rugged, with a very precipitous descent to the sea, King Peak having an elevation of 4,090 feet at a distance of about 2 miles from the shore.

POINT ARENA TO FORT ROSS.

From Shelter Cove to near Point Arena, the Rift, if continuous, lies beneath the waters of the Pacific. The continuity for this stretch is of course open to question, and in another place the considerations bearing upon this point will be presented. At the mouth of Alder Creek, 4.5 miles northwest from Point Arena, the Rift enters the coast from the sea and is thence traceable continuously to a point about 2 miles southeast of Fort Ross, a distance of about 43 miles, with a nearly but not quite straight course, being slightly curved with the convexity toward the ocean. (See map No. 2.) For our knowledge

A. Wood Gulch, Humboldt County. The Rift near its northern end. A. S. E.

B. Another view of the Rift. Wood Gulch. A. S. E.

A. The Rift above Shelter Cove, Humboldt County. A. S. E.

B. The Rift on the divide between the upper Gualala and the coast north of Fort Ross. H. W. F.

A. The Rift above Shelter Cove, looking northwest. The fault-trace follows old diastrophic features. F. E. M.

B. Northeast of Shelter Cove. Rift in the middle ground. F. E. M.

C. Looking up Garcia River along the Rift. F. E. M.

D. Looking up Garcia River along the Rift. F. E. M.

A. Characteristic Rift features southeast of Fort Ross. Figure on fault-trace. A. C. L.

B. Characteristic Rift features southeast of Fort Ross. Fault-trace in foreground. A. C. L.

of the features of the Rift for this part of its course, we are chiefly indebted to the observations of F. E. Matthes and H. W. Fairbanks. For this stretch its course is somewhat more meridional than the trend of the coast, so that it converges steadily southward upon the shore line, and finally intersects it below Fort Ross. Between the mouth of Alder Creek and the Garcia River the Rift is marked across a low, rolling country by a series of depressions, swamps, and ponds, many of which are without outlet. At the point where it intersects the Garcia River, the valley of the latter from that point upstream for a distance of 9 miles follows the Rift (plate 3C, D), and its course has with little question been determined by the structural conditions inherent in the Rift. On the southwest side of the valley the minor features of low ridges and swamps are common, and there are in places two sets of parallel ridges. From the head of the longitudinal valley of the Garcia, the Rift passes over a sag in the mountains to the Little North Fork of the Gualala River. From this point southeast, the Rift follows the common and very straight valley of the Little North Fork and the South Fork of the Gualala. This valley is separated from the coast by a ridge varying in height from 300 to about 1,000 feet. The Rift follows the valley, or rather the valley follows the Rift, for a distance of about 18 miles, and is characterized by the usual abnormal features of low ridges, with elongated swamps and ponds between, extended parallel to the river. The ridges again evince a tendency to appear in pairs, which is peculiarly marked near Stewarts. North of Plantation House the Rift passes over a broad, swampy divide in the coastal ridge (plate 2B), and at the House is marked by two small ponds. South of the Plantation House is a series of swampy hollows extending toward Buttermore's ranch. The latter lies in a broad, swampy saddle. From Buttermore's ranch southeastward the Rift is marked by a line of deformation traversing the uplifted wave-cut terraces and sea-cliffs which are notable features of this part of the coast. Low ridges with northeasterly scarps form barriers which pond the surface waters and give rise to numerous ponds and small swamps or elongated hollows. Several small ravines and gulches lie in its course, and occasionally a landslide is clearly related to the path of the Rift. In the vicinity of Fort Ross, the geomorphic forms of the Rift are particularly well exemplified and a typical stretch of the latter is cartographically represented on map No. 3. Low ridges up to 10 feet in height, some with mature rounded slopes, others with abrupt slopes to the northeast, mark its course. Alined with these are scarps which, by reason of their monoclinal slopes, can scarcely be called ridges. Behind the ridges and scarps are pools and small swamps. Some of the small streams follow the Rift and have established notable ravines along its course. (Plates 4 and 5.)

With regard to the geology of the territory traversed by the Rift from the vicinity of Point Arena to Fort Ross, Dr. H. W. Fairbanks has kindly examined the ground and supplied the following note:

Except for a strip of sandstones (Walalla beds) of upper Cretaceous age extending along the coast north and south of the mouth of the Gualala River, and a triangular area of Monterey shale and sandstone underlying the coastal terraces in the vicinity of Point Arena, the rocks of almost the entire mountainous region between the upper Russian River Valley and the coast belong to the Franciscan. There seems to be but one fault in this region, and that is on the line followed by the Rift. The Walalla beds begin upon the coast a little south of Fort Ross and, extending inland, form the ridge between the Gualala River and the ocean. The formation thins out against the ridge bounding the Gualala Valley upon the northeast. The line of junction is an irregular one, for in places the soft sandstones reach quite to the top of the ridge referred to. These beds extend along the coast to the northwest for more than 30 miles, finally terminating 7 or 8 miles south of Point Arena, where they are overlain by the Monterey sandstones and shales. The Rift does not follow the contact between the Walalla and Franciscan formations and the vertical displacement does not appear to have been very great, as in only one place was it enough to bring up the underlying Franciscan rocks upon one of its walls. The Rift, for something more than a mile after emerging from the ocean southeast of Fort Ross, lies in the Franciscan formation, and the latter is greatly

crusht and broken along it. Back of Fort Ross, the surface rocks traversed by the Rift belong to the Walalla formation, and from this point for a number of miles to the northwest no other formation appears.

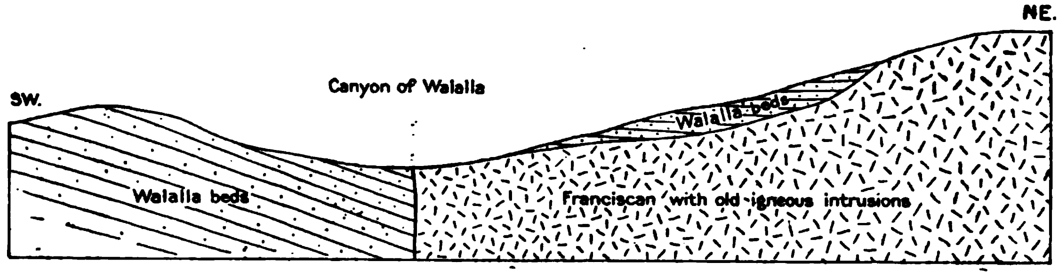


FIG. 1. — Geological section transverse to the Rift where it is followed by the Walalla (Gualala) River.

At the point where the road from Stewarts to Geyserville crosses the Gualala River, faulting and erosion have exposed the underlying Franciscan formation. This appears upon the northeast side, showing that the opposite side, that toward the ocean, has dropt. The Franciscan occupies but a narrow strip and is replaced for some distance up the ridge upon the northeast, by Walalla sandstones. These relations are shown in the cross-section sketch shown in fig. 1. Near the mouth of the Walalla River the formation upon the coast side of the Rift still appears to be the Walalla sandstones; the rocks upon the opposite side are buried under the alluvium of the valley. After leaving the valley of the Garcia River, the Rift lies wholly within the Franciscan formation until it disappears in the ocean. The Monterey shales with sandstones at their base form nearly the whole of the coastal terraced plain in the vicinity of Point Arena. They rest unconformably upon the Franciscan rocks and dip at a steep angle to the southwest. The Monterey formation nowhere appears to come in contact with the fault.

BODEGA HEAD TO BOLINAS BAY.

General Note. — From the point 2 miles south of Fort Ross where the Rift in its southeasterly course leaves the shore, it passes beneath the Pacific for a distance of 12 or 13 miles. Its observed course to the northwest of Fort Ross, if projected southeasterly with a slight curvature, would strike the shore again at Bodega Head; and here it is found on the low ground of the isthmus that connects the head with the mainland. The Rift here coincides in position with a fault described by Osmont,[1] whereby the Franciscan rocks to the east are dropt down against the pre-Franciscan dioritic rocks of the headland. Immediately to the east of the fault-trace is a marsh. Across the mouth of the bay formed by the headland is a sandspit and the fault-trace should cross the spit near its abutment upon the shore line, but the drifting sands preclude its finding an expression here in geomorphic forms.

To the south of Bodega Head the Rift follows Tomales Bay (plate 6A) to its head near Point Reyes Station. This is a remarkably linear inlet of the ocean lying between Point Reyes Peninsula and the mainland, having a length of about 15 miles and not exceeding a mile in width. It has generally been regarded as a feature determined by a fault,[2] the same as that noted by Osmont at Bodega Head, whereby the Franciscan rocks of the mainland were brought against the pre-Franciscan granitic and dioritic rocks of the peninsula. The bay is quite shallow, but both of the slopes above the shore line are rather precipitous, and the ridge crests on either side attain elevations of over 1,000 feet. On the mainland side of the bay there are some rather vaguely defined terraces, both in the form of wave-cut benches and delta embankments. On the same side of the bay there are marine deposits of late Pleistocene age, containing abundant molluscan remains which have been elevated to about 25 feet above sea-level, and which are the equivalent of similar deposits at a similar elevation on the east side of San Pablo Bay.

[1] Bull. Dept. Geol., Univ. Cal., vol. 4, No. 3.
[2] Cf. Anderson, Geology of Point Reyes Peninsula, Bull. Dept. Geol., Univ. Cal., vol. 2, No. 5.

A

B

C

D

Characteristic Rift features near Fort Ross. Old scarps accentuated by new fault. Undrained ponds. F. E. M.

To the south of Tomales Bay the Rift lies in a remarkable defile with abnormal and ill-adjusted longitudinal drainage, which extends thru to Bolinas Bay, a distance of about 14 miles. On the east side of the defile is the steep coastal slope of the mainland, rising to a ridge crest from 1,000 to 1,700 feet in height. The transverse gullies in this slope are shallow, and detract but little from the general effect of a fairly regular but uneven steep slope. On the west is an even steeper but more incised and rugged slope, which forms the eastern edge of the peninsular land mass. This slope culminates in crests having an altitude of about 1,500 feet. The most striking geomorphic feature of the bottom of the defile is the presence of low ridges with intervening ravines or gullies elongated parallel to the general axis of the depression. More or less hummocky surfaces, with hillocks and hollows having no regular orientation, also occur. In the hollows ponds are fairly common features. The chief drainage is to Tomales Bay by Olema Creek, which heads within 2.5 miles of Bolinas Lagoon; and the divide between this stream and the parallel one which flows to the southeast has an altitude of about 400 feet above sea-level. The southeast end of the depression is submerged beneath sea-level, and is cut off from Bolinas Bay by a sandspit. The very shoal water inside of the sandspit is known as Bolinas Lagoon. (See plate 6B.)

The rocks on the east side of the defile belong wholly to the Franciscan series. On the west side, at the north end, we have chiefly the granitic and dioritic rocks of the peninsula with limited masses of crystalline limestone into which these rocks are intrusive. Farther south the granitic rocks are overlain by the shales of the Monterey series, and these rocks form the west side of the defile for several miles. The shales have inconstant and often very high dips. Still farther south the sandstones of the Merced series lie unconformably upon the Monterey shales, and near the town of Bolinas dip uniformly at moderately low angles toward the axis of the defile. It is thus apparent that the axis of the defile crosses more or less obliquely or transversely the contact between the Monterey and the granitic rocks, and also the contact between the Merced and the Monterey. It is also a remarkable fact that altho on the east side of the defile the Franciscan rocks constitute the mountain mass to a thickness of several thousand feet, this entire series, together with the Knoxville, Chico, Martinez, and Tejon, is almost entirely absent between the Monterey and the granitic rocks on the peninsula in the immediate vicinity. This indicates clearly that in pre-Monterey time the peninsular mass had been uplifted on a fault along the present coastal scarp, so that the granite was brought against the Franciscan and denuded of its unconformable mantle of sedimentary strata before it was submerged to receive the deposits of Monterey time. It is also clear that inasmuch as there is a great volume of Monterey shales on the peninsular or seaward side of this fault line, and no trace of the same formation on the mainland to the east of the fault line, one of two things must have happened. Either the submergence which permitted the deposition of the Monterey shales was confined to the peninsula and was effected by a downthrow of that block on the same fault as that upon which it had earlier been upthrust, so that there was no sea over the territory east of the fault; or, if the regions on both sides of the fault were submerged together, then in post-Monterey time the east side of the fault was lifted into the zone of erosion and denuded of its covering of Monterey shales so thoroly that no trace of them now remains. There is no escape from one or the other of these conclusions, and each of them involves a movement on the fault with relative downthrow on the southwest side, or the reverse of that which occurred in earlier, pre-Monterey time. From this interpretation it follows that the defile extending from Tomales Bay to Bolinas Bay lies along the trace of a fault which dates from pre-Miocene time, and that upon this fault there have been large movements in opposite directions so far as the vertical component of such movements is concerned. The trace of this ancient fault is also the line of the modern Rift.

The dip of the Merced beds at Bolinas toward the Franciscan rocks of the mainland is quite analogous to the dip of the same beds toward the Franciscan of San Bruno Mountain on the San Francisco Peninsula,[1] and has the same significance, viz., that the Merced beds have been relatively downthrown on the west against the older rocks. The fault in the Tomales-Bolinas defile has usually been regarded as identical with and a continuation of the San Bruno fault of San Francisco Peninsula, and there seems to be no good reason for changing this judgment, altho, as will appear shortly, the modern Rift to the south of the Golden Gate does not coincide with the trace of the San Bruno fault, but leaves it at a small angle and pursues a course nearly parallel, but to the southwest of it. It is noteworthy, also, that while on the Point Reyes Peninsula, particularly in the vicinity of Bolinas, there is a magnificent wave-cut terrace at an altitude of about 300 feet, with a width of 1 to 1.5 miles between the base of its sea-cliff and the brink of the present sea-cliff, no such feature is to be found on the landward side of the fault-line on the coastal scarp between Bolinas Lagoon and the Golden Gate.

Characteristics of the Rift (G. K. Gilbert, pp. 30–35).— In a broad sense the structural trough in which lie the two bays is a feature of the great Rift. In a narrower sense the Rift follows the lowest line of the trough, controlling the topography of a belt averaging 0.75 mile in width. The physiographic habit of the trough is that of a depression occasioned by faulting. It is remarkably straight. One wall, the southwestern, is comparatively steep; the other is comparatively gentle. The gentler slope is an inclined plateau with incised drainage. Viewing the trough from any commanding eminence, the physiographer readily frames a working hypothesis of faulting and tilting. He sees in the southwestern wall a fault-scarp of moderate freshness, and in the northwestern wall a slope originally less steep, in which erosion has been stimulated by uplift and tilting. The general facts of the geology of the district, as worked out by Anderson,[2] agree with this theory. The axial line of the valley is recognized by him as the locus of a fault, or fault-zone, and the rocks of the southwest wall are everywhere older than those which adjoin them at the base of the opposite slope. The gentler slope is well shown by plate 7A. Plates 8B and 41B also show something of the gentler slope, and plate 7B of the bolder.

In a general way the two slopes are drained by streams which descend to the axis of the valley, and are there gathered in two longitudinal trunk streams which flow severally to Tomales Bay and Bolinas Lagoon; but in a central belt following the lowest part of the trough the details of drainage are comparatively complex, and their complexity is associated with peculiarities of the relief which serve to distinguish the central belt from the bordering slopes. In the bordering slopes the subordinate ridges conform in normal manner to the drainage, having evidently been developed by the erosion of the canyons which separate them. In the axial belt the ridges are evidently independent of the drainage, often running athwart the courses which would normally be followed by the drainage. In part the ridges divert or control the drainage; in part the drainage traverses and interrupts the ridges.

The influence of the ridges on the drainage is illustrated by the accompanying diagrams. Fig. 2 shows the actual drainage system; fig. 3 the system which would be developed if there were no special conditions along the axial zone. The small ridges of the axial zone trend parallel to the axis, and their interference gives parallel courses to various streams which would otherwise unite. The influence of the drainage on the ridges is illustrated by fig. 4, which shows a small ridge resting on the side slope of a larger ridge. The drainage of the larger ridge breaks thru the smaller, making gaps. Plate 7B shows the slope of a greater ridge at the right; and at the left two bushy hills

[1] Cf. A Sketch of the Geology of the San Francisco Peninsula. U. S. G. S., 15th annual report.
[2] Geology of Point Reyes Peninsula, by F. M. Anderson. Bull. Dept. Geol., Univ. Cal., vol. 2, No. 5.

which are part of a flanking ridge dissected by cross-drainage. The flanking ridge appears also in the distance. In plate 8A the flanking ridge is broader; in plate 9A it is more nearly a terrace than a ridge.

Similar relations between ridges and drainage lines are found in regions of steeply inclined strata, each ridge being determined by the outcrop of a resistant formation, or at least all of the preceding description might apply to the topography of such a region; but other characters remain to be mentioned, and these serve for discrimination.

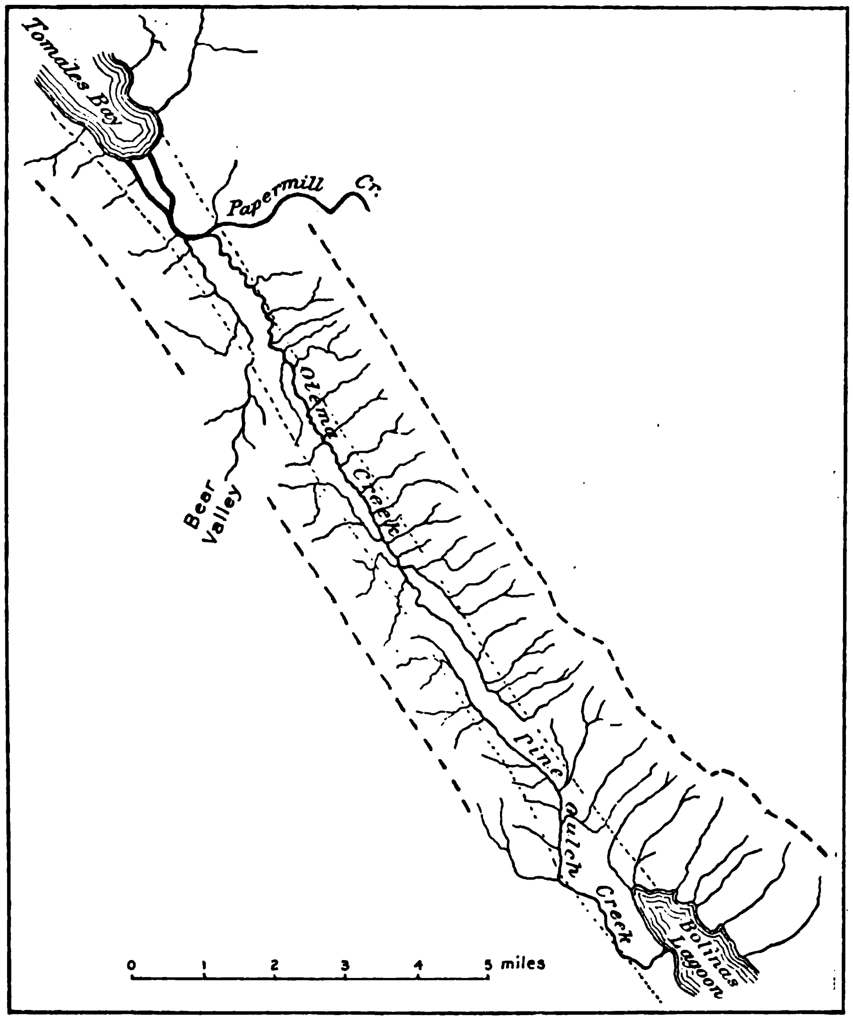


FIG. 2.—Drainage map of Bolinas-Tomales Valley. Heavy broken lines show crests of bounding ridges. Light broken lines indicate limits of Rift topography.

Where a steep-sided ridge is determined by the presence of a resistant formation, the determining rock follows and usually outcrops along its crest; but in the ridges under consideration there are few rock outcrops, and such as occur are not systematically related to the crest lines. The formation of the crest is not always the same thru the whole length of the ridge, and it is not always a rock of such character as to resist erosion. Between the ridges are linear valleys, and many of these are occupied by streams, but in a number of instances they are crost by the drainage. Often they include local depressions, with ponds or small swamps, this character being so pronounced that forty-seven such ponds were seen between Papermill Creek and Bolinas Lagoon, a distance of 11

miles. (See plates 9B, 10, 43, 54A.) The valleys range in width from 20 or 30 feet to about 500 feet, the majority falling between 100 and 200 feet; and each of them is approximately uniform in width, unless occupied by a stream. In a typical cross-profile, the side of the valley is somewhat definitely distinguished from the bottom by a change of slope (see fig. 5), the distinction appearing at one or both sides.

In view of these characters, and especially of the abundance of ponds, it is evident that these little valleys are not products of stream erosion; and that in so far as they are occupied by streams the streams are adventitious. Their true explanation is suggested by their relation to certain of the earthquake phenomena of April, 1906. As will

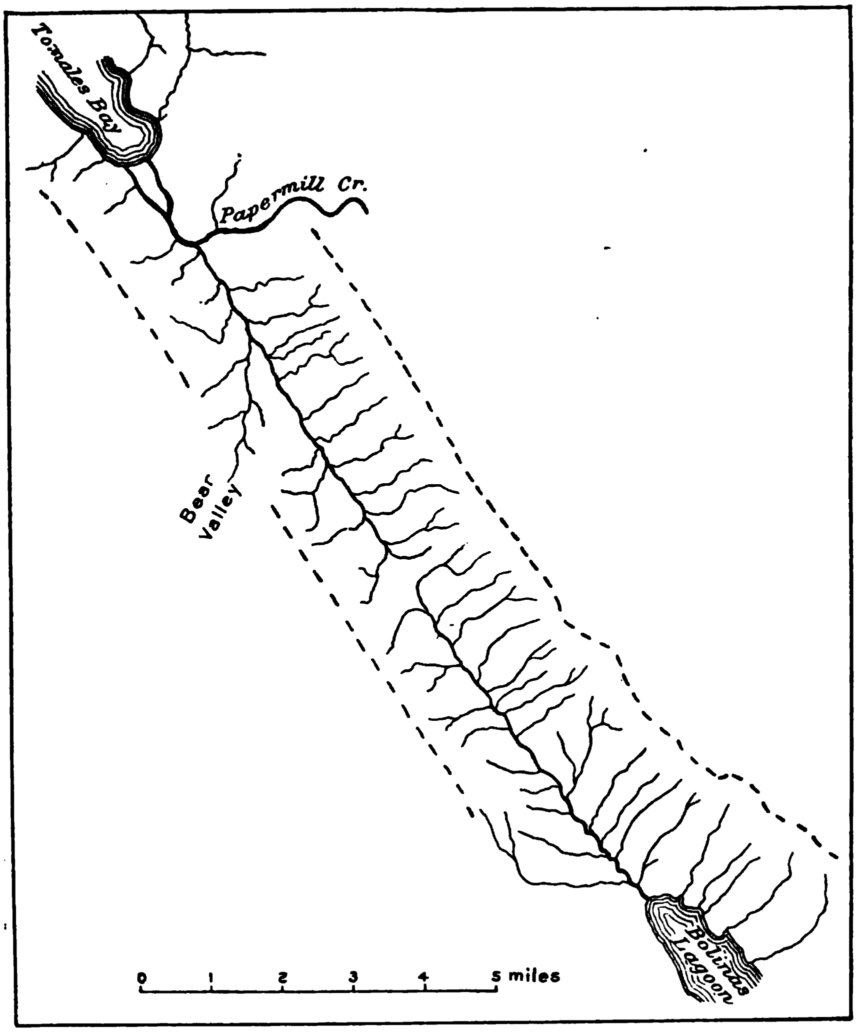


FIG. 3.—Hypothetic drainage map of Bolinas-Tomales Valley, if developed without influence of Rift displacement. Compare fig. 2.

presently be described in detail, the trace of the earthquake fault thru the greater part of its course in the larger valley follows the edge of one or another of these small valleys; and in places where the fault movement included vertical dislocation, such dislocation nearly always tended to increase the depth of the valley. (See plate 10B and fig. 6.) Of the numerous minor or secondary cracks developed by the earthquake in the immediate vicinity of the main fault, a considerable proportion occurred at the edges of the little valleys, following more or less closely the line along which the bottom meets the side; and with these cracks also there was usually a little vertical dislocation, the ground

A. Looking down Tomales Bay from near Olema. H. W. F.

B. Looking down Bolinas Lagoon and Bay toward the Golden Gate. Village of Bolinas in foreground. H. W. F.

A. Looking north in the Bolinas-Tomales Valley. G. K. G.

B. Fault-sag and side-hill ridge near Bondietti's ranch. The fault-trace follows sag and appears at left of field. G. K. G.

sinking a few inches on the side toward the middle of the valley. Thus the surface changes associated with the earthquake tended, within this belt, to increase the differentiation of the land into ridges and valleys; and it is easy to understand that the inception as well as the perpetuation of the ridges and valleys was due to faulting.

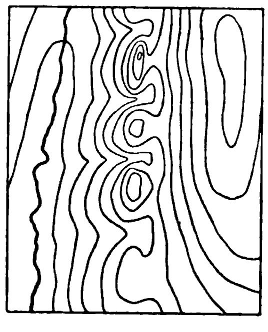


FIG. 4.—Map of side-hill ridge.

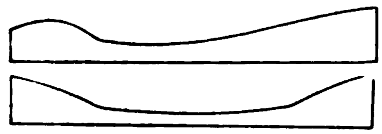


FIG. 5.—Cross-profiles of fault-sags.

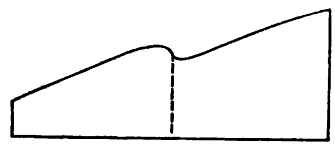


FIG. 6.—Cross-profile of side-hill sag shown in plates 7B and 10B.

Collectively these ridges and valleys occupy a belt from 0.5 to 1 mile in width, and constitute the local development of the Rift, using that term in its narrower sense. They make up the entire surface of the belt, except where overpowered by some vigorous creek. The individual ridges are not of great length, being 2 or 3 miles at the most, and usually much less. Some of them end by wedging out, others by dropping down until replaced in the same line of trend by valleys. Their greatest height above base, except where the adjacent valleys have been deepened by erosion, is about 150 feet. The narrower have straight, acute crests; the broader have undulating backs with more diversity of form than is shown by the associated valleys. Some are crost by curved or straight depressions, and these depressions have all the characters of the parallel valleys, including the association of earthquake cracks.

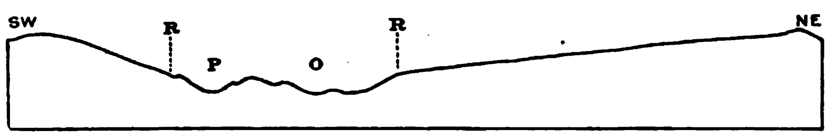


FIG. 7.—Cross-profile of Bolinas-Tomales Valley. Vertical and horizontal scales the same. RR = limits of Rift. P = valley of Pine Gulch Creek running SE. O = valley of Olema Creek running NW.

In the remainder of this report the term Rift will be applied only to the narrow belt just described. Regarding it as the surface expression of a great shear zone or compound fault, the ridges are the tops of minor earth-blocks, and the valleys are in part the tops of relatively deprest blocks and in part depressions resulting from the weathering of crusht rock. Considering the Rift as a physiographic type, I find it convenient to have a specific name for one of its elements, the small valley; and in some of the descriptions which follow I shall speak of it as a *fault-sag*. (See plates 7B, 8A, and 11.)

The general relation of the Rift to the greater valley is illustrated by the cross-profile in fig. 7. Along its northeastern side it everywhere lies lower than the adjacent slope of the greater valley, the produced profile of the valley slope passing above the fault-ridges as well as the fault-sags. Along its southwestern side some of the fault-ridges appear to project above the restored profile of the greater valley, while the fault-sags lie below. If I interpret the structure correctly, the great compound fault concerned in the making of the valley trough — a fault of which the vertical dislocation amounts to several thousand feet—includes a certain amount of step-faulting, which

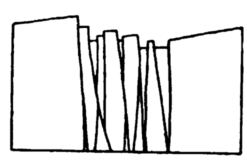


FIG. 8.—Ideal section across Rift corresponding to profile in fig. 7.

is responsible for some of the western ridges of the Rift belt; but with that exception, the ridges and sags of the Rift are occasioned by the unequal settling of small crust blocks along a magnified shear zone. (Fig. 8.)

The limits of the Rift are not definite. The boundaries drawn in fig. 2 serve to indicate the belt in which the Rift structure dominates the topography, but do not indicate the limits of the Rift structure. Within the belt the dislocations have been so re-

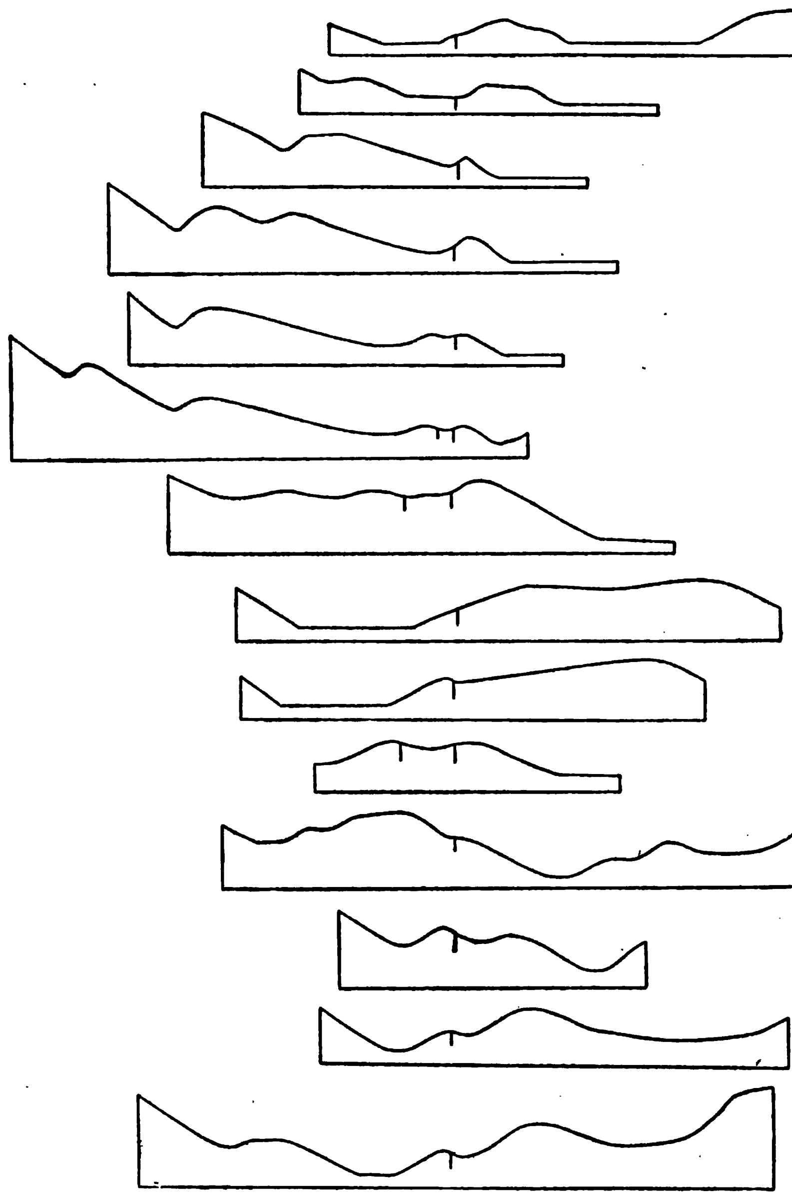


FIG. 9.—Cross-profiles of the Rift arranged in geographical order with the most northerly at top and northeast ends at the right. Positions of fault-trace and its branches are indicated. The profiles are copied from field sketches made without measurement.

cent and of such amount as to keep ahead of weathering and erosion, so that their expression has been little dimmed by the processes of aqueous sculpture. Outside the belt the evidences of recent dislocation are less striking, but nevertheless exist. The inter-stream ridges of the northeastern slope are here and there indented and creased in such a way as to indicate recent faults of small amount trending parallel to the Rift. In the vicinity

A. Fault-sag 6 miles south of Olema, looking northwest. The drainage crosses the sag from right to left. G. K. G.

B. Side-hill ridge 4 miles south of Olema, looking northwest.

A. Side-hill ridge 4 miles south of Olema, looking southeast. G. K. G.

B. Rift topography, with pond, a mile south of Olema, looking southeast. G. K. G.

A. Rift topography, with pond, near Bondietti's ranch, looking southeast. G. K. G.

B. The fault-trace near Bondietti's ranch, looking west. Illustrates the association of vertical displacement with fault-sags and ponds. G. K. G.

A. Fault-sag 2 miles south of Olema, looking southeast. G. K. G.

B. Fault-sag 3 miles south of Olema, looking southeast. G. K. G.

of both Bolinas Lagoon and Tomales Bay such features grade into dislocation terraces of greater magnitude, which originated at earlier dates but may have been recently accentuated. There are also narrow terraces of displacement on the comparatively steep face of the ridge southwest of the Rift, and at two points there are minor crests and associated canyons parallel to the main crest and to the Rift. So little is known of the local details of geologic structure that a different explanation of these creases, terraces, and spurs is not altogether barred; but their physiographic relation to the Rift features is so intimate as to leave little question in my mind of their genetic similarity. Assuming that they are correctly explained as the product of minor faulting of only moderate antiquity, they serve to connect the great trough containing the bays with the narrow belt of peculiar and striking topography, and indicate these as parts of a single great phenomenon — a belt which has been the locus of complicated fissuring and dislocation during the later geologic epochs.

MUSSEL ROCK TO PAJARO RIVER.

From Bolinas to the vicinity of Mussel Rock, about 8 miles south of the Golden Gate, the course of the Rift is beneath the waters of the Pacific, across the bar in front of the entrance to the harbor. Near Mussel Rock it intersects the shore at a great landslide (plate 12A) in rocks of the Merced series. At Mussel Rock, the basal beds of the Merced series rest directly upon an old land surface of worn-down Mesozoic rocks, and the basal bed contains abundant cones of *Pinus insignis* resting upon cemented alluvium. The cone-bearing bed immediately underlies marine strata and numerous fossils occur near the base of the series at the top of the ridge. The Merced strata here have a dip of about 15° to the northeast. The contact between the Merced and the older rocks trends southeast across the peninsula; and for some miles the Rift is approximately coincident with the trace of the contact and, for some portions of this distance, exactly so. From the shore line the course of the Rift is the same as that of the steep cliffs which rise at the back of the Mussel Rock slide to an altitude of over 700 feet. From the top of these cliffs, at an elevation of about 500 feet above sea-level, the course of the Rift as far as San Andreas Lake is marked by a line of shallow longitudinal depressions, ponds, and low scarps. (See plate 12B, 13, and 14.) There are eight ponds in this stretch of about 4.5 miles. This portion of the modern Rift was recognized as such in 1893.[1]

At a point about 4 miles from the Mussel Rock slide, the longitudinal depression which marks the course of the Rift becomes much more pronounced and passes into a remarkably straight and deeply trenched valley, the greater part of which has been converted by large dams into the San Andreas and Crystal Springs Lakes, used as reservoirs by the Spring Valley Water Company as water supply for the city of San Francisco. This straight valley (see plate No. 15) has an extent of 15 miles with a steady course of S. 34° E. to a flat divide southwest of Redwood City, whereby one passes over into the end of a similar but less pronounced valley, in which are situated Woodside and Portola. The San Andreas and Crystal Springs Lakes valley is almost wholly in the Franciscan terrane and the axis of the valley is discordant with the structural lines and contact planes of its constituent formations and intrusive masses. At the upper end of San Andreas Lake, however, the southwest edge of the Merced terrane forms in part the boundary of the valley on the northeast side for a short distance. The valley as a geomorphic feature (plate 16A) dates back fairly well into the Pleistocene. It is drained

[1] "The line of demarkation between the Pliocene and the Mesozoic rocks, which extends from Mussel Rock southeastward, is in part also the trace of a post-Pliocene fault. The great slide on the north side of Mussel Rock is near the land terminus of this fault-zone, where it intersects the shore line. Movement on this fault-zone is still in progress. A series of depressions or sinks, occupied by ponds, marks its course. Modern fault-scarps in the Pliocene terrane are features of the country traversed by it." The Post-Pliocene Diastrophism of the Coast of Southern California, by Andrew C. Lawson, Bull. Dept. Geol., Univ. Cal., vol. 1, No. 4, pp. 150–151.

by San Mateo Creek which flows in a sharp gorge thru the wider part of the broad, flat-topt ridge which separates the valley from the Bay of San Francisco. This stream is regarded as a relic of the original consequent drainage of the northeast slope of Montara Mountain, which became superimposed upon the Franciscan terrane by the denudation of the overlying soft and little coherent Merced formations. From this consequent trunk the valley in which San Andreas and Crystal Springs Lakes now lie was evolved by subsequent erosion along the line of the Rift, its present features dating from a period in the Pleistocene later than the removal of the Merced formations. A small portion of the upper end of the valley has been captured by the headwater erosion of San Bruno Creek.

To the southeast of Crystal Springs Lake, the valley followed thus far bifurcates about 2 miles beyond the lake, on either side of a median ridge. The two branches are nearly parallel. The east branch rises to a wide and rather flat divide, with streams heading in it from both sides. The other branch, altho it is more incisive, has no well-defined stream, but has a small swamp at its lower end. It rises to a sharper divide, from which there is a descent into the narrow straight canyon of West Union Creek. It is this western depression that the Rift follows. Near Woodside the canyon of West Union Creek expands into a more open valley, with steep mountains on the southwest and lower hills on the northeast. The Rift follows this straight valley (plate 16B) to its southeastern end, and then ascends to the saddle which separates Black Mountain from the mountains to the west. From this saddle it descends to the narrow canyon of Stevens Creek. It crosses the canyon at a small angle near its upper end and parallels the creek on the southwestern side, at an elevation of about 500 feet above it. It then passes thru the saddle between Stevens Creek Canyon and Congress Springs, and keeps well up on the slopes to the west of Congress Springs behind a series of shoulders and knolls to a reservoir on a saddle thru which it passes. From this saddle southeastward the line of the Rift again lies along the southwest side of a longitudinal valley and so continues on a line independent of the present drainage to the pronounced notch in the crest line of the range at Wright Station.

In this stretch of the Rift from Crystal Springs to Wright, the coincidence of the Rift with the major geomorphic features is very striking for the first half of the distance. In the second half, if we judge by the fault-trace, it appears to be quite independent of, tho parallel to, the canyons; and its only manifest relationship to the geomorphic features is its coincidence with a series of saddles or windgaps in the transverse spurs of the mountains. Its general parallelism with, and proximity to, the crest of the range thruout the entire stretch is pronounced. In the notch at Wright, the Rift intersects the crest line and passes from the northeastern flank of the range to the southwestern.

The general features of the Rift from Wright to Chittenden are described by Mr. E. S. Larsen in the following note:

From the hills above Wright Station to the village of Burrell, a distance of about 2 miles, the Rift follows along the ridge above Los Gatos Creek, which drains to the east. The drainage of the western slope of the ridge is to the Pacific. For most of this distance the Rift is a short distance on the Los Gatos Creek side. It usually occupies a small, trough-like depression; or, where it cuts just above the heads of the small gullies, there are low, rounded knolls between the gullies. These knolls are seldom over 30 feet higher than the trough. Just southeast of Burrell, the Rift traverses the ridge and follows a gully into Burrell Creek, which it crosses. It continues in a southeasterly direction, parallel to the creek and about halfway up the ridge to the southwest of it. The elevation of the ridge is only about 400 or 500 feet above the creek bed, and the top is rounded, with a steep slope below this to the Rift, and a gentle slope below the Rift

A. Great landslide at Mussel Rock, where the Rift enters the Coast from the Pacific. H. O. W.

B. Looking northwest along the Rift. The landslide is just beyond the house. H. O. W.

A

B

Characteristic ponds along the Rift southeast of Mussel Rock. H. O. W.

PLATE 14

A

B

C

D

Features of the Rift between Mussel Rock and San Andreas Lake. H. O. W.

to the creek. Near Burrell the slope is very gentle at the Rift, for from 20 to 50 feet, but is steep above and below. Looking up the Rift and the creek from this point, one gets the impression of a long straight creek, but in reality the view is over the divide, down a small tributary of Soquelle Creek to its junction with the main stream and thence up the main Soquelle Creek. About 2.5 miles from Burrell the Rift follows a small gully into Soquelle Creek, which it crosses where the creek makes a sharp turn to the west. For the next 4 miles, or to the point where the new county road crosses the divide between a branch of Soquelle Creek and Eureka Creek, it follows near the top of the timbered ridge to the southwest of Soquelle Creek. The heavy timber obscures the topography, but the Rift, wherever crost, is marked by a bench or trough on the hillside.

Following the Rift to the southeast, it passes at the divide into the head of Eureka Canyon, rises on the northeast bank, and slowly gets farther away from the creek, cutting across the tributary creeks and rarely following one of the smaller gulches for a short distance. The typical section here gives a steep slope on the high hills to the northeast, then about 0.25 mile of gently sloping, rolling hills, and finally the steep slope to the creek itself. The Rift is on the gentle slope, generally at some distance from either of the changes in slope. This continues for about a distance of 2 miles on to Grizzly Flat. Here the high steep hills to the northeast are separated from the lower hills to the southwest by a flat about 500 feet across. The Rift is on this flat near its center, and usually marks the northeast boundary of a series of low knolls. It continues on the flat for about 0.5 mile to where the hills close together and leave a rather steep-walled gulch. The Rift follows up this gulch for about a mile, and then crosses into the head of another creek, which it follows down for about 3 miles, where the stream turns sharply to the north. For the upper mile the gulch is rather sharp and deep, but at Hazel Dell the hills on both sides are low and rolling, while the lower mile is again rather steep, opening at the turn to a rather flat country. At Hazel Dell and other points, the Rift occupies a small but distinct trough very near the southwest bank of the creek. From here to Chittenden, a distance of about 8 miles, it follows parallel to Pajaro Valley, well up on the hills, and cuts across the canyons at almost right angles.

The typical section up one of these ridges gives a gentle slope from the valley to an elevation of about 1,000 feet; a steep slope for about 50 feet in the opposite direction, which marks the Rift; a very gentle slope for about 1,000 feet across; and finally, the steep upper slope of the hills. Over this area the Rift is nearly always marked by a trough, which often gives rise to a small lake perched on a ridge between two steep canyons. At a few points, especially about a mile northwest of Chittenden, small streams and gullies tend to follow the Rift, and they then make a sharp turn where they leave it. At Chittenden the Rift again passes thru a pronounced notch in the crest of the range occupied by the canyon of Pajaro River (plate 17A), from the western flank of the dominant ridge of the Santa Cruz Range to the eastern flank of the Gavilan Range.

The rocks traversed by the Rift from Mussel Rock to Pajaro River are, so far as known, almost wholly confined to the Franciscan and Monterey series, the former prevailing in the northern part and the latter occurring only in the southern. At Pajaro River the Rift encounters the granitic rocks of the Gavilan Range, but these lie wholly on its western side.

PAJARO RIVER TO THE NORTH END OF THE COLORADO DESERT.

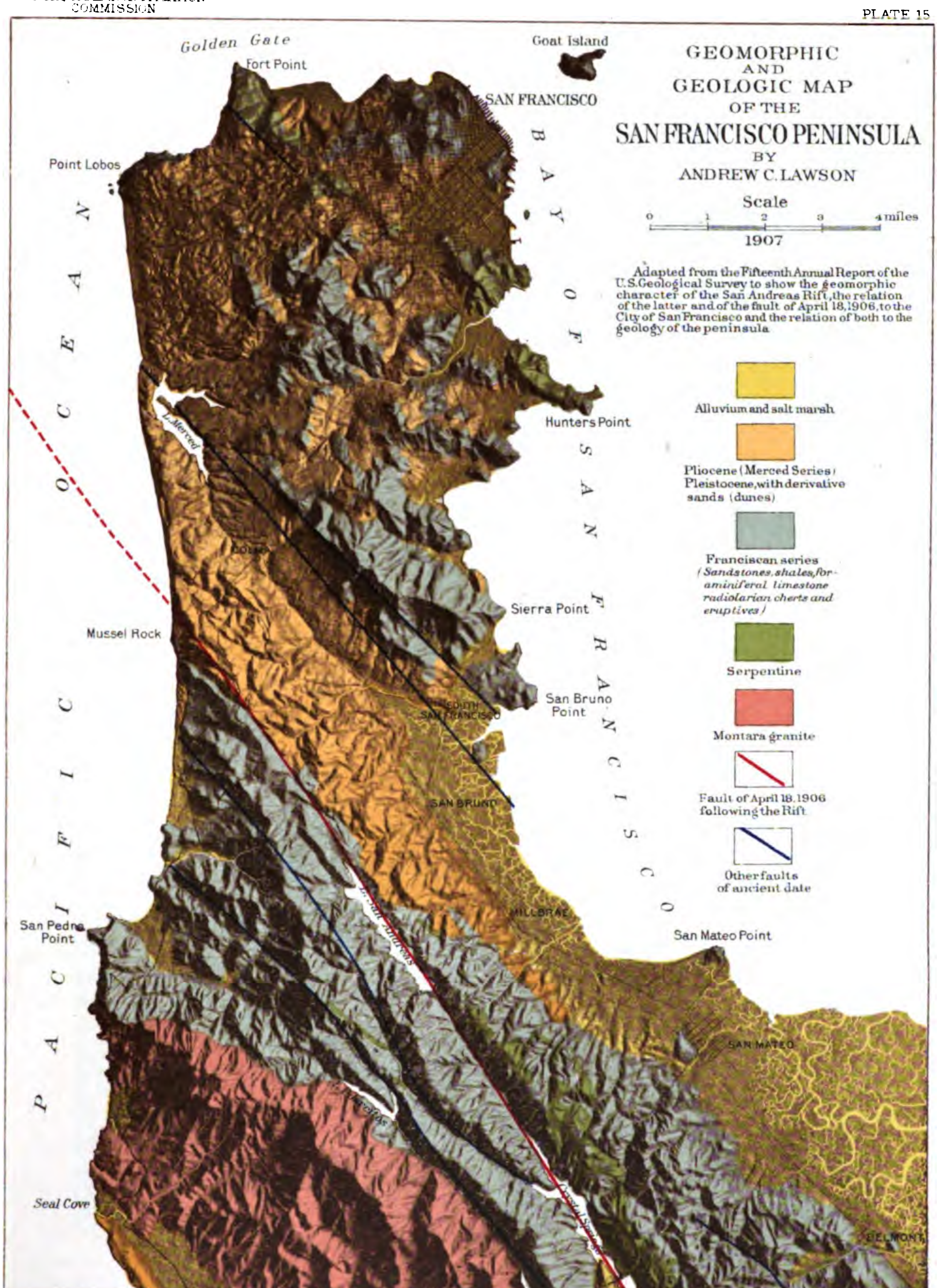
By H. W. Fairbanks.

The earthquake of April 18, 1906, opened and displaced the walls of the old fault along the Rift as far south as the town of San Juan in San Benito County. The fault-trace passes directly under the western span of the Southern Pacific Railroad bridge across San Juan River, as shown by the displacement of the piers at the end of the bridge, a distance of 3.5 feet. For a distance of nearly half a mile on either side of the bridge, the river has established itself in the Rift. To the northwest the steep slopes of Mount Pajaro facing the canyon do not show any regular fissure. This does not, however, indicate any discontinuity in the fault, for the surface of the whole mountain is more or less broken by auxiliary cracks, secondary fissures, and slides.

Southeast over the hills from the point where the Rift leaves the river, the characteristic features of the Rift make their appearance. It is marked by a small pond (plate 17B), springs, and a more or less continuous ridge with its steeper face toward the southwest. The fissure of the recent earthquake follows this series of features (plate 18A), and, at a point halfway between the bridge and San Juan, there is shown in a broken fence a horizontal displacement of 4 feet. A mile before reaching San Juan, granitic rocks are exposed upon the southwest side of the Rift. Shortly beyond this point the Rift leaves the hills and traverses the western edge of the valley of the San Benito River. The ridge which we have been following is now lost in the level floor of the valley, but as far as traceable its course is directly toward the low bluff upon the eastern edge of the town of San Juan. The fissure of the recent earthquake is to be seen where it crosses the road 0.5 mile northwest of San Juan, but has not been noted farther along the old Rift line. It appears to bend more easterly, and this probably connects it with the disturbances of the earth between Hollister and San Juan. Mr. Abbe, of San Juan, states that the earthquake of 1890 opened the old Rift and that the displacement of the walls, tho small, was in the same direction as in the recent earthquake.

The town of San Juan stands upon a bench of gravel which dips gently in a southwesterly direction, but upon its northeastern side presents a steep face which, near the old mission, has a height of about 50 feet. This bluff is marked thruout its length of 0.5 mile by several springs; and there can be little doubt that it owes its existence to a fault movement uplifting and tilting toward the southwest a portion of the floor of the valley, and that it thus originated in the same way as other similar features which we shall find to be characteristic of the Rift. The Rift leaves the valley southeast of San Juan and gradually rises along the eastern slope of the Gavilan Range. It intersects the head of San Juan Canyon, and has here given rise to an interesting modification of the drainage. San Juan Canyon is long and narrow and is formed by the union of several small streams which, rising upon the higher slopes of the range, pursue a normal course toward the San Benito Valley, until reaching the Rift, they turn northwest and slightly away from the fracture line, giving rise to San Juan Canyon. At the point where the Rift intersects the canyon, the narrow ridge between the canyon and the valley has been broken thru, and the whole drainage passes directly down the mountain, abandoning the canyon, which is now filling with débris fan material.

For about 10 miles southeast from the head of San Juan Canyon, the Rift follows the eastern slope of the Gavilan Range. It is marked by small valleys and gulches, by hollows and ridges upon whose sides oak trees are growing; and it is followed almost continuously by a wagon road. One of the most interesting features along this portion of the Rift is Green Valley, a broad cienega due to the filling up with gravels and silt of a valley lying close under the steeper portion of the Gavilan Range. There are two fault-lines below the valley and about 0.25 mile apart. The cienega is due to vertical



JULIUS HIEN & CO N.Y.

A. The Rift valley between San Andreas Lake and Crystal Springs, looking southwest. Fault-trace parallel to fence about 50 feet beyond. Auxiliary cracks in the foreground at an angle of 40° with it. J. C. B.

B. The Rift valley 5 miles west of Stanford University. Fault-trace in foreground. Per J. C. B.

A. The Rift followed by the Pajaro River at Chittenden. Dislocated bridge supported by false work. H. W. F.

B. The Rift a mile southeast of Chittenden. Pond on upper slope of hill. H. W. F.

displacement along the upper line, which has raised a ridge of the old crystalline rocks across the valley. This dam must first have given rise to a lake, but as this filled up with the wash brought down from the mountains, a marshy meadow took its place. The oldest resident in the district says that the earthquake of 1868 formed a small lake in the lower portion of the cienega. The great body of gravels filling the old valley acts as an important reservoir of water. The city of Hollister has taken advantage of this fact to secure a water supply. By tunneling thru the rock barrier, the gravels are reached and the water led away in pipes.

The Rift comes out upon the San Benito River 4 miles above Paicenes P.O. For several miles up the river from this point, the Rift line is masked by the recent flood plain. Above Mulberry P.O., and just before coming to the bridge across the river, a most striking and interesting feature appears. Upon the east side of the river, and separated from it by a ridge, is a narrow depression half a mile long and 75 feet deep, without any external drainage. The ridge between it and the river extends a mile northwest of the sink, and presents a steep face to the northeast. The road passes along the eastern base of the ridge and opposite the sink makes use of its even crest. The river makes a sharp bend at the bridge, and the Rift crosses to the west side. Faulting has here brought to the surface, upon the west side of the Rift, limestones associated with the crystalline schists and granitic rocks of the Gavilan Range.

In order to follow the Rift beyond the mouth of Willow Creek, we leave the San Benito River road at the mouth of the creek and follow to its head a long narrow canyon which has evidently been eroded on the line of fracture. At the head of the canyon we come out upon a bit of open rolling country which, but for a low ridge, would drain into the San Benito. This ridge has evidently been raised along the Rift, diverting a stream which would naturally be tributary to the San Benito, so that now it forms the head of Bear Creek and flows down past the Chelone peaks into the Salinas River. Several undrained hollows (plate 18B) mark the Rift as it follows the ridge between Bear Valley and San Benito River. The formation of both walls is probably of Tertiary age up to a point near San Benito P.O., where the Franciscan series constitutes the southwest side and the Tertiary the northeast. South of San Benito P.O., there is a considerable area where the surface has been much changed as a result of some one of the movements along the old Rift. A fertile valley, perhaps 0.5 mile long, appears to have been formed thru subsidence, while on the southwest is an abrupt ridge 200 feet high and fully a mile long. The ridge without doubt has been produced by faulting. Its abrupt northeastern face and long, gentle, southwesterly slope suggest in a remarkable manner the great fault blocks of the west, such as the Sierra Nevada Range. The ridge gradually sinks in a southeasterly direction, blending with Dry Lake Valley. The latter is about 2 miles across and has no external drainage. The fault-scarp already mentioned extends as a low ridge part way across the valley and is utilized by the road.

Looking southeast across the valley in the direction which the Rift pursues, a mountain is seen which seems to have been sharply cut off. Descending a narrow valley to the southeast of Dry Lake Valley, we reach the foot of a steep escarpment (plate 19A) where there are apparent two, and possibly three, lines of displacement. The middle one passes at the foot of the main cliff, which is between 400 and 500 feet high. It can not be said with certainty that the whole cliff is the result of faulting, altho it is certainly so in part. The formation in the cliff is sandstone of either Tertiary or Cretaceous age. About 5 miles northwest of Bitterwater there is an interesting valley which has been so disturbed that it has no external drainage, while thru its center passes a ridge formed along the Rift. The ridge forms a fine roadbed. Descending toward Bitterwater Valley and P.O., another ridge appears which is as even and regular as a railroad grade. Bitterwater Valley is occupied during the wet season by a marshy lake.

The depression is probably associated in some manner with one of the movements along the Rift. Upon the eastern edge of the valley there is an escarpment about 100 feet high, due to an upward movement upon the northeast side of the Rift.

Southeast of Bitterwater, the Rift leaves the younger formation, and at Lewis Creek both walls are in the Franciscan rocks. For 20 or 25 miles now, the peculiar features of the Rift by which we have followed it are almost absent. The Franciscan series, including old sedimentary rocks, serpentines, and other basic igneous rocks, does not lend itself well to the preservation of such records, but appears to be greatly broken and crusht and marked by enormous landslides in the vicinity of the Rift. The Rift crosses Lewis Creek about 2 miles above its mouth and then passes up over a high ridge lying between Lewis Creek and San Lorenzo Creek. On the north side of Lewis Creek there is an enormous landslide, which has nearly blocked the valley. The slide is undoubtedly hundreds of years old. The ridge on to which the Rift passes after leaving Lewis Creek is crost by it at such a small angle that it does not reach the southern base until we get to the head of Peach Tree Valley, a distance of 20 miles. The ridge its whole length is shattered and broken, and, as before said, marked by innumerable rockslides. The rather steep slopes appear to move every wet season. The headwaters of the San Lorenzo Creek (Peach Tree Valley) have been robbed by Gaviota Creek, possibly as a result of some movement connected with the Rift. Just above where the stream has been diverted, there is another great landslide which the road crosses to reach Slack Canyon.

At the mouth of Slack Canyon, the Rift leaves the Franciscan series, and coincides again with an ancient fault in which the Miocene sandstones are thrown down upon the southwest against the older formation just referred to. Passing from Slack Canyon over a divide, we come to the headwaters of Indian Creek and Nelson Canyon. As the Rift occupies steep slopes much of this distance, it is distinguished chiefly by landslides and rapid gullying of the surface. In Nelson Canyon the Rift follows an old fault in which the Miocene formation has been thrown down upon the southwest side, and the northeast wall so raised that the granite on which the Franciscan series rests is exposed. Ascending the divide toward the head of Nelson Canyon, a long, nearly straight ridge of Miocene clays divides the drainage and appears to be due to some one of the movements along the Rift.

The Rift can be traced thru the hills at the head of the Cholame Valley by its characteristic features, as well as by bluffs which are undergoing rapid erosion. It crosses the road a mile west of Parkfield and exhibits here a regularly rounded ridge 200 feet wide and 20 feet high at the most elevated point. (Plate 19B.) That the ridge must be hundreds of years old is shown by the great oak trees that are growing upon it. One white oak is fully 8 feet thru. Large springs mark the fissure at this point, and are found along it the whole length of the Cholame Valley. According to a resident, the Rift opened along the ridge in the earthquake of 1901, the opening being distinctly traceable for several miles. Southeasterly from the point just described thru the Cholame Valley, there appears no very prominent ridge or escarpment, altho springs and cienegas, marking a gentle swell in the flat open surface of the valley, indicate the line of the Rift.

The region about Parkfield, in the upper Cholame Valley, has been subjected to more frequent and violent disturbances than almost any other portion of the entire Rift. An auxiliary fissure begins near the main Rift a little west of Parkfield, and extends in a more easterly direction along the east side of Cholame Creek. (See plate 20.) The once flat, open valley has been broken along this line, and a bluff nearly 200 feet high formed facing the Creek. This bluff, now deeply eroded, must have been formed during one of the oldest disturbances. The lowland between this bluff and Cholame Creek shows the effect of great disturbance over a considerable area. Innumerable hollows interlace and extend in all directions. They resemble nearly obliterated creek beds except that they have no outlets. Parallel with the front of the dissected bluff, but a little back from

A. Looking northwest along the Rift 3 miles southeast of Chittenden. H. W. P.

B. Ponds along Rift near San Benito. H. W. P.

A. The Rift 2 miles south of Dry Lake Valley, San Benito County. H. W. F.

B. Ancient scarp on the line of the Rift a mile west of Parkfield, Cholame Valley. H. W. F.

A. A branch of the Rift 2 miles southeast of Parkfield, Cholame Valley. H. W. F.

B. Another view of the same. H. W. F.

A. Rift, northeast side Carissa Plain. A. C. L., Jan., 1906.

B. Rift, northeast side Carissa Plain. A. C. L., Jan., 1906.

C. Rift, northeast side Carissa Plain. A. C. L., Jan., 1906.

D. Rift, just beyond southeast end Carissa Plain. A. C. L., Jan., 1906.

E. Rift, just beyond southeast end Carissa Plain. A. C. L., Jan., 1906.

F. Rift, just beyond southeast end Carissa Plain. A. C. L., Jan., 1906.

its upper edge, are two parallel lines of faulting, probably made at a later date than the bluff itself. A small lake occupies a hollow in one. The slopes of one of these V-shaped depressions are quite steep, pointing to a comparatively recent origin.

The people living along the Rift for 150 miles southeastward from the Cholame Valley tell wonderful stories of openings made in the earth by the earthquake of 1857. The first settler in Cholame Valley was erecting his cabin at that time, and it was shaken down. The surface was changed and springs broke out where there had been none before. In 1901 a fissure opened in the road which crosses the branch fault just described. After each successive shake it is reported that the fissure opened anew, so that the road had to be repaired again in order to be passable.

Upon the western side of the Cholame Valley, near its southern end, the main Rift again exhibits an interesting bluff which cuts off the débris fans of the back-lying hills. This bluff faces northeasterly. Where the Rift crosses the creek as it passes out of the Cholame Valley, a low escarpment was formed upon the west side which must for a time have dammed the creek and given rise to a lake. From the outlet of the Cholame Valley the Rift line can be seen as it rises along the low rolling hills, and disappears over their tops. It is marked by a distinctly steeper slope facing northwesterly, showing that an uplift of 30 to 50 feet took place upon the west side. The region traversed thru the Cholame Valley southeast to the Carissa Plain and for some miles beyond, exhibits no older formation than the Miocene Tertiary, the effects of older faulting, if such has occurred here, being masked by recent deposits. Continuing the examination toward the southeast, the writer came upon the Rift at the northern end of the Carissa Plain, 4 miles northeast of Simmler P.O., and in direct line with its course where last seen. Here the width of the broken country is much greater than usual, being nearly a mile. A number of lines of displacement can be distinguished; some nearly obliterated, others comparatively fresh. This is a region of light rainfall and of gentle, grass-covered slopes, presenting just such conditions as would preserve for hundreds of years the effects of moderate displacements.

The Rift zone continues to be traceable along the western base of the Temblor Range, finally passing out on to the gently rolling surface of the eastern edge of Carissa Plain. Broken and irregular slopes, cut-off ridges, blocked ravines, and hollows which are white with alkaline deposits from standing water mark the Rift. Carissa Plain has a length of about 30 miles. About halfway the Rift begins to be marked by a low and nearly obliterated bluff upon its northeastern wall. This is at first little more than a succession of ridges or hills cut off on the side next to the level plains. These detached ridges finally become connected in a regular line of hills with a steep but deeply dissected slope toward the southwest and long gentle slopes toward the northeast. This ridge is clearly a fault block, and now separates the southeastern arm of Carissa Plain from Elkhorn Plain. It probably originated during some one of the earlier movements along the Rift; in fact, it is reasonable to suppose that it is of the same age as other important scarps which mark the Rift thruout its whole course, and which came into existence as a result of some mighty movement opening the earth for several hundred miles.

Except for one slight bend, the ridge which we have been describing follows a straight course toward the southeast for a distance of nearly 20 miles, finally blending in a much larger mountain-like elevation. This has a height of perhaps 500 feet above the sink at its southern base. Its deeply dissected front is in line with the front of the ridge already described and the two appear to have originated together. The steeper face is deeply sculptured into gullies and sharp ridges, while the back slopes off gently toward the southern end of Elkhorn Plain. Plainly visible along the steep front of the line of hills described are the lesser ridges and hollows produced during the last violent earthquake in this region, probably in 1857. (See plate 21A, B, C.)

A gentle divide separates the southern end of the Carissa Plain from a long narrow sink extending along the Rift line toward the southeast. (Plate 21D, E, F.) This sink includes an area 6 miles long and in places its drainage is fully 3 miles wide. Several depress alkali flats, covered with water during the wet season, receive the scanty run-off of this dry region. These depressions are several hundred feet wide and are bordered upon opposite sides by quite sharp bluffs, in some places 100 feet high. The phenomena suggest the sinking of long narrow blocks between two walls. This reach of 6 miles between the ranches of Job and Emerson is one of the most interesting areas examined. The larger scarps belong to some ancient disturbance, while the last one, probably dating from 1857, is marked by features comparatively insignificant.

As we ascend the long grade from the sinks just described, to Emerson's place, near Pattiway P.O., the Rift features become smaller and less regular, altho easily followed. (See plate 23A.) At Emerson's the Rift passes thru a sag in the hills and across the head of Bitter Creek. It then rises and crosses a flat-topt hill between this creek and the west fork of Santiago Canyon; and descending to the east fork keeps along the steep mountain slope upon the south until it finally crosses the divide between San Emedio Mountain and Sawmill Mountain. Thru this section the Rift gradually bends toward the east, and in Cuddy Canyon, farther east, it has an east and west direction for a few miles.

The Rift itself is scarcely distinguishable in Bitter Creek and Santiago Canyons, owing to steep slopes and rapid erosion, as well as numerous landslides. Santiago is one of the deepest and narrowest canyons in this portion of the mountains. Its whole southern slope, that traversed by the Rift, has been more or less affected by slides producing many little basins along the edge of the flat-topt divide between the drainage into the San Joaquin Valley and Cuyama River. Huge masses of earth and rock are still moving, as shown by fresh cracks and leaning trees. In one place the edge of the divide has split away in such a manner as to produce long narrow ridges with depressions behind them, closely imitating the real Rift features. Santiago Canyon marks a great fault of earlier times. Soft Tertiary formations are faulted down thousands of feet upon the south side of the canyon, while upon the north appear the steep granitic slopes of the western spur of San Emedio Mountain.

The Rift appears upon the north side of the pass which leads from Santiago Canyon to San Emedio Canyon. Two lines of disturbance are here plainly visible. Going down the west branch of San Emedio Canyon, the Rift zone is plainly traceable, but nowhere does it form important features. Passing to the east fork of the canyon, we continue on the line of the Rift to the divide leading over to Cuddy Valley. (See plate 22A.) Beginning upon the divide, a broad rounded ridge, fully 50 feet high upon its southern side, extends down the slope in a direction a little south of east. Cutting thru the center of this ridge longitudinally is a deep V-shaped depression, as tho a movement later than that which formed the ridge had opened a fissure thru its center. On the sides of the ridge, as well as the slopes of the fissure in it, large pine trees are growing in an undisturbed condition. Continuing down the ridge, we find that in the course of a mile it gives place to an escarpment facing northerly. A valley 4 miles long and 0.5 mile wide lies below the escarpment and contains meadows and a small lake without any outlet. Springs mark the Rift line. The escarpment has been much eroded, but toward its eastern end it has a height of nearly 300 feet and is covered with a growth of pine trees among which are stumps of large dead trees in an undisturbed condition. The valley and the bluff are doubtless the product of the earliest movement in the epoch of which we are treating. The last movement left a comparatively small ridge traceable here and there along the base of the greater.

Continuing on the line of the Rift, we enter and pass for 10 miles down Cuddy Canyon.

A. Looking south-southeast along the Rift toward Cuddy Valley from head of San Emedio Canyon. H. W. F.

B. Old fault-scarp in Rift. East end of Cuddy Valley. H. W. F.

A. Looking northwest along the Rift from Emerson's place, near Pattiway. H. W. F.

B. Looking east along the Rift from Gorman Station. The low scarp was probably made in 1857. H. W. F.

A. Pond and scarp in Rift east of Gorman Station. H. W. F.

B. Lower Lake Elizabeth. In the Rift. H. W. F.

A. Looking southeast along the Rift between Lake Elizabeth and Palmdale. H. W. F.

B. Looking east along the Rift scarp west of Palmdale. H. W. F.

(See plate 22B.) The fissure follows its northern side for several miles and then, bending a little toward the south, crosses the canyon and takes a course for Tejon Pass. The granitic mountains upon the north of the canyon rise with exceedingly steep slopes, the rocks of which have been thoroly shattered. Immense quantities of rock débris have been brought down the gulches, building up in the main canyon a succession of large and steep débris fans. So much débris has been carried down the canyon that it has been blocked at the point where it turns toward old Fort Tejon, and has thus given rise to Castac Lake. The Rift crosses the divide at the gap known as Tejon Pass. Here there are features due to two movements. Descending a few hundred feet, we find ourselves in a long valley, extending about 10 miles in a direction a little south of east. Springs, marshes, and two ponds mark the line of the Rift from Gorman Station easterly. (Plates 23B and 24A.)

At German Station, several miles below Gorman, there is a wonderfully regular ridge forming a marsh. In this vicinity the earthquake of 1857 is reported to have done much damage, shaking down an adobe house and breaking up the road. The little lake upon the divide halfway between Gorman Station and Neenach P.O. is due to débris brought down from the hills upon the south thru which the Rift zone passes. The Rift follows a very regular and straight course, a little south of east, along the mountain slopes south of Antelope Valley. Thru the most of the distance, as far as Palmdale, it occupies a series of valleys shut off by considerable elevations from the open slopes of Antelope Valley. After traversing the northern slopes of Libre and Sawmill Mountains, the Rift crosses the head of Oak Grove Canyon, then another small canyon with branches eastward and westward along the break, and eastward of this a long canyon opening out to the fertile valleys about Lake Elizabeth.

Lake Elizabeth and Lower Lake (plate 24B) are both due to the blocking of the drainage of two valleys extending along the Rift. These valleys lie on the slope of the range toward the desert (Antelope Valley), but their outlet is southward by a narrow canyon thru the heart of the mountains lying between the desert and Santa Clara River. A low escarpment along the southern side of the valley in which Lake Elizabeth lies, and eastward, is replaced by a lofty rounded ridge which appears to be due to some one of the movements along the old fault. For several miles east of the lake (plate 25A) the distinctive and characteristic features of the Rift are not as easily made out, altho the ridge just mentioned is full of springs and exhibits a widespread landslide topography. Toward the eastern end of this ridge small hollows and a low, indistinct escarpment again appear. The ridge separates Leones Valley, a fertile and well-watered district 5 or 6 miles long, from the open Mojave desert on the north.

From Leones Valley to and beyond the point where the Rift zone crosses the Southern Pacific Railway, a constant succession of cienegas is found on the upper side; that is, on the side toward the mountains. Movements have evidently been so often repeated and so intense along the Rift as to grind up the rocks and produce an impervious clayey stratum, bringing to the surface the water percolating downward thru the gravels of the waste slopes. A mile west of Alpine Station on the Southern Pacific Railway, there begins another escarpment with its abrupt face toward the south. This extends to and across the railroad. South of the escarpment the surface has sunk so as to form a basin. (Plates 25B and 26A.) This has been artificially enlarged and used as a reservoir for irrigation about Palmdale. The main escarpment is 40 to 50 feet high in places, and where the railroad crosses it there appear to be two, an older and a younger one. From the summit of the ridge marking the Rift west of Alpine, an extensive view eastward is obtained. The long desert waste plain leading up to the foot of the mountains on the south (San Gabriel Range) exhibits a strikingly interesting feature. It is not continuous across the line of the Rift, but shows a break with the uplift upon the lower side. The amount of displacement appears to be between 200 and 300 feet.

An extended study would be necessary to determine in detail the geology of the Rift from Gorman Station eastward. Near Gorman a dike of basaltic or andesitic lava extends parallel with it for some distance. Granitic rocks often form one side, while soft Tertiary beds of a light or reddish color frequently appear in the raised ridges. Between Palmdale and Big Rock Creek, low discontinuous ridges, springs, and cienegas point out the line of the Rift, altho there are stretches of several miles at a time where either the original displacement was not great or erosion has removed its effects. Four miles west of Big Rock Creek there is one fine escarpment 0.333 mile long and 40 feet high, facing the mountains on the south. (Plate 27A.) In this section there are indications of at least two movements. (See plate 26B.) The Rift passes just below Big Rock P.O. east of Big Rock; a trail on the northern slope of the mountains and a wagon road on the southern side of the divide follow the Rift continuously to a point near the mouth of Cajon Canyon. On the north side of the mountains (San Gabriel Range) there is no important depression on the Rift between Big Rock Creek and Swartout Valley; nevertheless the comparatively recent movements have been of sufficient magnitude to produce ridges and hollows giving a continuous and easy route for the trail along the slope of the mountains.

Before reaching the divide leading over to Swartout Valley, we encounter some striking features. Near the head of Mescal Canyon a ridge has been split away from the mountain, diverting the little streams from above and making two drainages where one would normally appear. In places this ridge (plate 27B) is as sharp and as perfect as tho formed but yesterday; but the great pine trees, growing upon its top and sides (the altitude here being nearly 7,000 feet), tell us that it must be hundreds of years old. At the head of the canyon the trail leads thru a sharp V-shaped cut where the bare sliding surfaces make it appear as if movement had recently taken place in the Rift. (See plate 28A.)

Passing over a sag in the mountains to Swartout Valley, the Rift is less prominent as a topographic feature, but a line of springs marks its course. Lone Pine Canyon is remarkable for its length and straightness. The Rift passes down its whole length but it is not very prominent. Springs appear at several points, also small cienegas with a slight escarpment below them. At the mouth of Lone Pine Canyon and a little above its junction with the Cajon Canyon (plate 28B) are more interesting features. Two lines of displacement appear here, and between them a long, narrow sunken block with a small lake in its lowest portion. (See plate 29A.)

The line of disturbance now crosses Cajon Canyon, giving rise to broken and sliding cliffs; and then, passing over a spur of the San Bernardino Range, comes out at its foot before reaching Cable Canyon. From this point the Rift continues on southeasterly at or near the junction of the gravel slopes of the San Bernardino Valley and the steep mountain slopes of crystalline rocks. The uniformly straight course which the Rift exhibits in this portion of its length takes it diagonally across the mountains from the northern and desert side of the San Gabriel Range to the southern side of the San Bernardino Range.

The torrential streams emerging from the San Bernardino Range upon the gravel slopes of the broad valley at its base have cut wide flood plains in the ancient gravels which accumulated along the foot of the mountains. The remaining portions of this old slope lying between the stream plains are called mesas. Back of Devore Heights there appears a rounded ridge formed out of the mesa gravels. As we continue toward Cable Creek, springs and cienegas are found to be numerous just above it. East of Cable Creek the ridge becomes an escarpment facing the valley, and in places shows a height of about 75 feet. Viewed in profile, this escarpment breaks the uniform slope of the mesa gravels, almost reversing their slope on the upper side. On the west side of Devil Canyon there is a double escarpment in the gravels, both apparently being due to movements along the Rift. (See plate 29B.) Back of the Muscupiabe Indian reservation and north of the

A. Sink between 2 scarps of the Rift a mile south of Palmdale. H. W. F.

B. Pond in the Rift 2 miles west of Big Rock Creek, Mojave Desert. H. W. F.

A. Fault-scarp in the Rift. Mojave Desert west of Big Rock Creek. H. W. F.

B. Ridge in the Rift near the head of Swartout Valley. H. W. F.

A. The Rift across the mountain crest west of Swartout Valley. North slope of San Gabriel Range. H. W. F.

B. Looking southeast from lower end of Lone Pine Canyon across lower end of Cajon Canyon. Lake and meadow due to ridge in Rift. H. W. F.

A. Looking west along the Rift from Cajon Pass, showing double scarp. H. W. F.

B. Double fault-scarp in Rift north of Highland, at base of San Bernardino Range. H. W. F.

Asylum, there is a much dissected fault cliff 200 to 300 feet in height. Plainly traceable in the front of this cliff is a small break, possibly made in 1857. No definite information could be gained as to whether the earth opened here at that time, but reports say the earthquake was very severe, throwing animals from their feet, etc.

East of City Creek begins a huge rounded ridge formed in the mesa gravels, and this can be traced nearly to Plunge Creek. This ridge is 150 feet wide and steeper upon its upper side, where the greatest displacement shown is about 40 feet. The structure and shape of the gravel ridge make it appear likely that faulting and folding were both concerned in its making. Above this ridge and at the highest point where it crosses the mesa, water is obtained in abundance for irrigation at a depth of 18 to 20 feet, while in the mesa below the ridge no water is found at a depth of 200 feet.

The Santa Ana River has cut out a wide stretch of the mesa gravels, and has exposed upon its eastern bank a good section of these gravels. The gravels at their upper edge do not lap over the crystalline rocks but appear faulted down against them. A 0.25 mile below the fault is the mouth of Morton Canyon, the stream issuing thru a long, narrow canyon eroded in the mesa gravels. Morton Canyon emerges from the steep mountains about 2 miles to the southeast and has taken this peculiar course thru the gravels to the Santa Ana River, instead of flowing directly down across them, as do all the other streams. The explanation of the turning to the northwest of this canyon at the point where it meets the gravels is found in the peculiar appearance of the gravel slope when viewed in profile. This, instead of rising with normal slope, becomes steeper toward the upper edge, and then descends abruptly to Morton Canyon. The movement on the Rift has broken and lifted up the gravels to such an extent that the waters of Morton Canyon were diverted and turned down to the Santa Ana River along the upper side of the ridge. Since this displacement took place, they have had time to cut the canyon in which they are now flowing. Southeast of the point where the Rift crosses Mill Creek, the peculiar topographic features which have characterized it for so many miles become very indistinct. It was at first thought that the Rift terminated in this vicinity but closer examination made it clear that such is not the case.

The southern portion of the San Bernardino Range lying between Mill Creek and the Conchilla Desert appears to have undergone great disturbance at a recent date. As a consequence, erosion has been rapid and extensive, and surface features which farther north made the Rift easy to follow have in this region been almost completely obliterated. Potato Canyon extends along the line of the Rift to the southeast of Mill Creek. Its features indicate that the history of the fault is a complex one. The canyon originated thru erosion upon the fault contact between the crystalline rocks of the San Bernardino Range and the older Pleistocene deposits along its base. Following this period of erosion was one in which gravels were again deposited and this was succeeded by the present period in which erosion is active. Potato Canyon is the last of the longitudinal depressions of any size marking the line of the Rift. Between its head and the desert to the southeast the main drainage features pay little attention to the structural conditions, because of the steep grades of the stream channels and consequent rapid erosion. Nevertheless small lateral canyons have been formed along the fault contact of the gravels with the crystalline rocks of the higher portion of the San Bernardino Range, so that from the proper viewpoint the fault line can generally be traced in the topography. The drainage of Potato Canyon is clearly influenced by the fault, for instead of there being one stream course in it, there are two — one upon each side.

A mile southeast of Oak Glen, which is at the head of Potato Canyon, there are large springs which issue upon the line of the fault. Near this point a depression appears upon a gravel ridge, where it meets the crystalline rocks. The depression is in line with the course of the fault, and may with reason be attributed to dislocations similar to those so

clear farther north. Two miles southeast of Oak Glen is Pine Bench, a mesa-like remnant of gravel having an elevation of about 5,000 feet. At the northern edge of this mesa, and upon the line of the fault, there is a regular escarpment facing the higher mountains. It is most reasonable to interpret this as indication of the same displacement referred to previously.

To the east of the San Gorgonio River, the topography as shown upon the San Gorgonio quadrangle gives little indication of the presence of an important fault-line. However, an examination of Potrero Creek shows small transverse canyons and one broad, grassy flat with springs upon the line of the fault. In Stubby Canyon and other small canyons north of Cabazon Station, the fault is finely shown. Here, as at the point where the Santa Ana River issues from the mountains, the older Pleistocene gravels have been faulted down against the crystalline rocks. Rapid erosion of both the Pleistocene deposits and the crystalline rocks has given rise to steep and precipitous slopes in this section, and upon these the fault is clearly shown. The schists and gneisses thru a width of hundreds of feet adjoining the fault have been so crusht by pressure and movement that they quickly crumble upon exposure. Dark clay marks the plane of movement which inclines to the north at an angle of about 80 degrees. Later than the period of main faulting has come an elevation of the range as a whole, giving rise to rapid erosion upon both sides of the line of fracture. Remnants of gravel mesas and mature topographic forms appear in places. A notable example of an area of old topographic features now being destroyed by the modern canyons is shown to the west of Stubby Canyon and 1,000 feet above it.

There are traces here and there of recent displacements along the Rift. These are of the nature of little sags without outlets and low ridges or escarpments not easily explainable as a product of ordinary erosion. These may have arisen as the product of landslides, but the landslides themselves are doubtless related to fault movements. The great débris fans built up along the north side of San Gorgonio Pass indicate rapid removal of a vast amount of rock material from the adjoining slopes of the San Bernardino Range consequent upon recent uplift.

Before investigating this region it was thought that the Rift, if it continued on southeasterly, would be found crossing the San Gorgonio Pass in the neighborhood of Cabazon and skirting the eastern base of the San Jacinto Range; but this proved not to be the case. Instead, it was found to turn more and more easterly and finally to extend parallel with the pass without reaching it. The course of the Rift, then, instead of being in the direction of the Salton Sink, is toward the Conchilla Desert north of Palm Spring Station.

Looking east from a point near the mouth of Stubby Canyon, the gravel mesa thru which the Whitewater River issues from the mountains, appears to be faulted upward, giving rise to a well-defined escarpment facing north toward the crystalline rocks. This northward facing escarpment accords in relative position with the traces of escarpments farther north near Oak Glen, and shows that the latest displacement has been the reverse of the earlier. The last seen of the Rift is in the sides of the Whitewater Canyon, where the gravels are faulted down against the crystallines. East of the Whitewater one enters upon the Conchilla Desert over which has been spread the wash of Mission Creek. For a distance of 6 or 8 miles, and perhaps much more, the bedrock is completely buried by the recent accumulations.

The San Bernardino Range rapidly decreases in height to the southeast of Mission Creek, but appears to be continuous with the desert range lying north of the Salton Basin. The latter range of crystalline rocks appears to be separated from the lowlands of the basin by a more or less continuous line of barren yellow hills formed of soft late Tertiary rocks. Judging from a cursory examination, these yellow hills are separated from the higher mountains behind by a structural break indicated by a series of longitudinal valleys. A prolongation in a northwesterly direction of the supposed fault line indicated by these

A. Looking east across Borego Valley toward south end of San Jacinto fault-scarp. H. W. F.

B. A nearer view of the San Jacinto fault-scarp. Upper end of Borego Valley. H. W. F.

valleys would carry it into the San Bernardino Range at the point where Mission Creek emerges upon the wash plain. Continuing still farther northwest, we follow a marked topographic break which leads across the southern slope of San Gorgonio Peak to the head of Mill Creek. It is very probable that the great fault followed so far joins the above fault-line at some point easterly from Palm Spring Station, altho the many miles of gravel-covered desert makes a positive statement impossible with present knowledge.

An examination of the northerly and easterly base of San Jacinto shows conditions opposite to those characterizing the southern slope of the San Bernardino Range. Erosion is generally slow upon the slopes of San Jacinto, while the rapid erosion from the opposite side of San Gorgonio Pass has crowded the stream channels close to the base of the former range. In fact, the base of the San Jacinto Range appears to be deeply buried by the stream deposits. The desert face of San Jacinto has long been free from disturbances. Long, jagged ridges project out into the desert, while the intervening canyons, instead of furnishing material for extensive débris fans, are floored by accumulations characteristic of the desert as a whole.

Toward the southern end of that spur of the San Jacinto Mountains which projects into the Colorado Desert and is known as the Santa Rosa Mountains, the débris fans are larger and remains of gravel deposits appear high up on the sides of the mountains. The only suggestion that a fault traverses the Salton Basin in the direction of the mouth of the Colorado is the presence of mud volcanoes and several small pumiceous eruptions near the center of the basin. These are, however, so far removed from any known fractures in the crust that their evidence is of little value. Besides, it is entirely possible that the mud volcanoes may be due to chemical action in the deeply buried sediments of the Colorado delta.

It may be reasonably assumed, then, from our best knowledge, that the southern end of the great Rift is to be traced for an unknown distance along the base of the mountains bordering the Salton Basin upon the northeast, in all probability gradually dying out.

SAN JACINTO FAULT.

The San Jacinto fault (plate 30), with which there has been associated at least one severe earthquake since the region has been known, has a length of at least 75 miles. The course of the fault is northwest and southeast, and it is marked by canyons or steep mountain scarps nearly its whole length. The fault first appears upon the south in the form of a regular mountain wall inclosing the north end of Borego Valley. The latter is a western arm of the Colorado Desert lying between the Santa Rosa Mountains and the main watershed of the Peninsular Range. At the northern end of Borego Valley beds of late Tertiary age appear faulted down upon the southwest side of the mountain wall referred to. The peculiar topographic features of this fault-block ridge, and the presence of gravels along portions of its summit, make it appear of recent origin. Northwest of Borego Valley the canyons entering Coyote Creek have brought down immense quantities of rock débris, a fact which indicates recent disturbance along their headwaters. Terwilliger Valley includes a broad expanse of country of low relief upon the summit of the range between San Jacinto and Borego Valley. A portion of the valley is scarcely drained at present, having apparently undergone some subsidence next to the fault-line which forms the southern face of Mount Thomas.

In a northwesterly direction, the fault can be traced in continuous mountain scarp or canyon until within about 8 miles of the town of San Jacinto. A broad valley intervenes until we get north of the town, when a mountain wall commences again, and extends for many miles in the direction of Colton. Reports state that the San Jacinto earthquake of 1899 was most severe along the line of the fault thus traced. Great masses of rock are

reported to have been thrown down in Palm Canyon, which issues from San Ysidro Mountain. Ten miles southeast of San Jacinto, on the line of the fault, it is said that a considerable area of land sank with formation of open fissures. Upon the Coahuila Indian Reservation, adobe buildings were thrown down and much damage was done in the town of San Jacinto.

The regular mountain wall facing southwest and extending northwest from San Jacinto appears to be older than that toward the southern end of the fault. Mineral springs occur near or on this line, and the marshy area at the point where the San Jacinto River ceases following this fault-scarp and turns toward the southwest suggests very strongly a subsidence.

REVIEW OF SALIENT FEATURES.

It will be of advantage briefly to review the salient features of the San Andreas Rift, in the light of the facts presented in the foregoing detailed description of its extent and character, and of other facts to which attention will be directed.

The San Andreas Rift has been traced with three interruptions from a point in Humboldt County, between Point Delgada and Punta Gorda, to the north end of the Colorado Desert, a distance of over 600 miles. These three interruptions are: The stretch between Shelter Cove and the mouth of Alder Creek, where for a distance of about 72 statute miles it traverses the bottom of the Pacific Ocean; the stretch from the vicinity of Fort Ross to Bodega Head, where for 13 miles it is similarly on the ocean bottom; and the stretch from Bolinas Lagoon to Mussel Rock, where it lies beneath the Gulf of the Farallones for about 19 miles. Of these interruptions only the first involves any doubt as to the continuity of the feature, and this doubt is in large measure removed by the evidence cited hereafter as to the position of the trace of the fault of April 18, 1906.

Thruout its extent the Rift presents a variable relation to the major geomorphic features of the region traversed by it. In Humboldt County it lies within the mountainous tract inland from the coast but to the seaward side of the higher land. From Shelter Cove to Alder Creek it lies to the west of a steep, terraced, coastal slope. From Alder Creek to Fort Ross, it finds its expression in a series of rectilinear, sharply incised valleys, the alinement of which converges upon the coast line to the south at a very acute angle. But near Fort Ross the Rift, without deviation of its general trend, crosses the divide to the coastal side of the ridge which separates these valleys from the ocean, and traverses the terraced coastal slope. Beyond Fort Ross it again lies to the west of a steep coastal slope. From Bodega Head to Bolinas Lagoon the Rift is a remarkably pronounced depression, lying between the main coastal slope and the rather high and precipitous easterly side of the Point Reyes Peninsula. About 0.6 of this depression is below sea-level, forming Tomales and Bodega Bays. This defile is one of the most remarkable and interesting phases of the Rift. It has been a line of repeated faulting in past geological time, and evidently separates a well-marked and probably relatively mobile crustal block from the main continental land mass.

South of Mussel Rock the Rift traverses for a few miles a rolling upland, marked by ponds and old scarps, but with no very marked contrast in relief, and then passes into the very marked and rectilinear San Andreas Valley, along the base of the northeast flank of the Santa Cruz Range. From here to the gap at Wright Station it lies along the base of the range at a distance nowhere greater than 2 miles from the crest. Passing thru the gap at Wright, it crosses from the northeast flank of the range to the southwest flank. Similarly passing thru the gap between the Santa Cruz and Gavilan Ranges at Chittenden, it is again found on the northeast flank of the latter. In effecting this last-mentioned change of position relatively to the mountain crests, a distinct deviation in the trend of the Rift is observable (see map No. 5) as if the path of the Rift accommodated itself to

the mass of the mountain blocks. Farther south, near Bitterwater, the Rift leaves the northeast flank of the Gavilan, and lies along the southwest base of a straight ridge of the Mount Hamilton Range. Still farther south in Cholame Valley it follows the northeast base of the ridge which separates Cholame Valley from San Juan Valley. In the Carissa Plain it hugs the southwest flank of the Temblor Range. But the most noticeable reversal of the relative position of the Rift to the adjacent mountain slopes is beyond Tejon Pass. From Tejon Pass to near Cajon Pass, the Rift lies along the steep northerly flank of the San Rafael and San Gabriel Ranges, on the southern edge of Mojave Desert; but at Cajon Pass it passes thru between the San Gabriel and San Bernardino Ranges, and thence easterly lies on the south side of the latter range. Thus from the San Francisco Peninsula to its southern end, so far as the extent of the Rift is at present known, there is a fairly regular and rather remarkable alternation of the relative positions of the Rift and the mountains adjacent to it.

The Rift as a whole, when plotted upon a general map of the state on a scale of about $\frac{1}{1000000}$, appears as a sensibly even line with marked curvature, convex toward the Pacific. This curvature is for the most part due to change in the course of the Rift between the southern end of Carissa Plain and Tejon Pass. In this segment of its course its trend changes from about S. 40° E., along the edge of Carissa Plain to S. 65° to 70° E., along the southern edge of the Mojave Desert, the change being gradual and distributed over an arc about 40 miles in length. The general curvature is also accentuated by the change in course between Point Arena and Shelter Cove, on the assumption of continuity between these points. If, however, we take the segment of the Rift between Point Arena and the south end of Carissa Plain, the curvature is very much less marked; and its path on the small scale map referred to approximates a straight line. The curvature is distinct, however, and, as in the general case, is convex to the Pacific. The chord of the arc found by stretching a line from the south end of Carissa Plain to the mouth of Alder Creek has a bearing of about N. 40° W. and a length of about 360 miles. The point on the arc most distant from this chord is on a normal to the latter thru San Jose, the distance being about 15 miles.

When the Rift is plotted on larger scale maps (see maps Nos. 2, 4, 5, 21, and 23), it becomes apparent that the course of the Rift is not a smooth uniform curve, but is characterized by several minor curvatures in opposing directions. In locating these curves, advantage is taken of the fault-trace, as far as it extends, as a sharp line within the Rift indicating its mean trend at any point on its course. These curvatures are most interesting features on a line of diastrophic movement, where that movement may be, as it was on April 18, 1906, essentially horizontal on a nearly vertical plane or zone.

The most northerly curvature susceptible of measurement is that shown by the segment of the Rift between the mouth of Alder Creek and Fort Ross. The line connecting the two ends of this segment, at the points where it intersects the shore line, is a little more than 43 miles in length, and has a bearing N. 37° W. The Rift, as located for this purpose by the fault-trace, lies wholly on the southwest side of this chord. The bearing of the fault-trace at the mouth of Alder Creek, where it converges upon the chord, is N. 30° W., and at Fort Ross its bearing is N. 40° W. The fault-trace is at its maximum distance from the chord about the middle of this segment, the distance being about 0.75 mile, and here the bearing of the Rift is sensibly the same as that of the chord, N. 37° W. Between Fort Ross and Bodega Head, where the Rift passes under the Pacific, there is probably a slight reversal of this curvature; since, if the course of the fault-trace at Fort Ross were continued, even as a straight line, it would pass to the eastward of the point where it actually intersects the neck of the headland. This slight concavity to the southwest probably extends as far as the mouth of Tomales Bay. From Bodega Head south thru Tomales Bay to Bolinas Bay, the course of the Rift as a large geomorphic feature is

practically straight, with a bearing of N. 37° W., for 35 miles; but there are slight curvatures in the fault-trace within the Rift. For example, the fault-trace, in its path thru Tomales Bay, must be slightly convex to the southwest to clear the little headlands on the northeast side of the bay, as it apparently does. There is a similar slight convexity to the southwest between the head of Tomales Bay and Bolinas Bay. The complementary concavity between these two convexities is near the head of Tomales Bay.

Between Mussel Rock and San Andreas dam, the fault-trace has a slight concavity to the southwest. The projection of its course seaward from Mussel Rock would not meet the southward projection of the fault-trace from Bolinas. There can be little question as to the continuity of the fault-trace across the Gulf of the Farallones; and its path on the bottom of the Gulf must, therefore, take the form of a very flat sigmoid curve, with a slight concavity to the southwest in the Bolinas moiety of the submarine segment and a corresponding convexity at the Mussel Rock end. Between San Andreas dam and Chittenden, the fault-trace indicates a pronounced curvature in the general trend of the Rift. The chord between these two points is about 55 miles in length and bears N. 44° W. The fault-trace lies wholly to the southwest of this line, with convexity toward the Pacific. The point on the curve most distant from the chord is about its middle part, the distance being about 2.25 miles. On this segment of the Rift there is locally a rather abrupt reversal of the curve, south of Black Mountain, which is best seen on map No. 22.

Between Chittenden and a point near Priest Valley there is another pronounced curvature in the general course of the Rift, where it passes over to the northeast flank of the Gavilan Range. Here the curvature is concave toward the southwest. The chord is 60 miles long, and bears, as before, N. 44° W., and the Rift lies wholly on the northeast side. The point on it most distant from the chord is near the middle of the segment, and the distance is 2.4 miles. From Priest Valley to the south end of Carissa Plain, the Rift is nearly straight, but with minor curvatures which can not be more particularly defined, owing to the absence of good maps. The general bearing for this segment is about N. 40° W.

The marked curvature between the south end of Carissa Plain and Tejon Pass has already been noted. From the latter place to the north end of the Colorado Desert, beyond which the Rift has not been traced, there are numerous curvatures in the course of the Rift; but since the Rift for this segment is indicated on maps Nos. 6 to 15 on a scale of 1 or 2 miles to the inch, it will be unnecessary to do more than refer to these maps for their characterization. The general course of the Rift in this region is a flat curve concave to the south-southwest.

It thus appears that the Rift, as a whole, has a curved course convex to the Pacific; and that this general curvature is characterized by a succession of slightly curved, rather than straight, segments. The amount of the curvature, as it appears upon the maps, is determined to some slight extent by the character of the projection. But the general conclusion above reached without quantitative expression is independent of the projection adopted for the maps.

A most interesting general feature of the Rift is in relation to the granitic rocks of the Coast Ranges. The granites of the southern Sierra Nevada pass into the Coast Ranges in the vicinity of Tejon Pass, and extend thence in a series of more or less elongated but discrete areas thru the Santa Lucia, Gavilan, and Santa Cruz Ranges, and beyond the Golden Gate to Point Reyes Peninsula and Bodega Head. From the southern end of Carissa Plain to Bodega Head, this granite lies wholly to the southwest of the Rift. At one point in the Rift, however, in Nelson Canyon, Fairbanks has found the granite exposed on the northeast side of an old fault having a downthrow on the southwest. Southward it passes into a region where granitic rocks prevail on both sides of the Rift. The Rift in the Coast Ranges thus appears to serve as a line of demarkation between two

somewhat contrasted geological provinces; one in which granitic rocks are extensive and important features, and the other in which granitic terranes are wanting. This fact further suggests that the two provinces will be found to be contrasted in other respects when the details of the Coast Range geology are better known. The general fact is indicative of relatively greater uplift on the southwest side of the Rift, and consequently deeper denudation, whereby the rocks of the granitic complex have been stript of their covering and so exposed to view. In that portion of the Coast Ranges south of the Bay of Monterey, the Santa Lucia Range along the coast is much higher than any of the other ranges which intervene between it and the great valley.

In a discussion of the Rift as a geomorphic feature, it becomes a matter of interest to determine the relative importance of diastrophism and erosion in its evolution. There can be no doubt that where the Rift is coincident with pronounced longitudinal valleys, the latter, altho controlled as to orientation by the faulting along the Rift, owe their features in a large measure to erosion. This is true, for example, of the valleys of the Garcia and Gualala Rivers and the San Andreas Valley. It is not so clear, however, as regards the depression between Point Reyes Peninsula and the mainland. It has been pointed out that in past geological time there has been a recurrence of faults with large vertical displacement on this portion of the Rift, dating back to pre-Miocene time and possibly to the Cretaceous; and it may be that here the depression is essentially diastrophic in origin and only modified to a minor degree by erosion; similarly with some of the valleys along the Rift, and extending from it in the Southern Coast Ranges. The Cholame Valley and the valley of Carissa Plain may be essentially diastrophic in origin, modified by erosional degradation on their sides and by aggradation of their bottoms. The depressions which constitute the Rift along the southern margin of Mojave Desert appear to be practically wholly diastrophic, altho somewhat aggraded. Where the Rift hugs the steep northeast flank of the Santa Cruz Range as far as Wright Station, and the similarly steep southwest flank of the same range from Wright to Chittenden, it is difficult to avoid the conclusion that these steep mountain flanks are in reality degraded fault-scarps, and are, therefore, the walls proper of a great asymmetric Rift valley. The same conclusion applies to the steep north flank of the San Rafael and San Gabriel Ranges, on the south side of Mojave Desert. The complete discrimination of effects of diastrophism and erosion in the larger features of the relief associated with the Rift will require many years of patient field work.

With regard to the minor features which characterize the Rift in detail, thruout its extent, the discrimination is less difficult chiefly because the diastrophic effects are of comparatively recent date and their distinctive features are not yet obliterated by the ravages of erosion. These consist chiefly of scarps, low ridges, and sinks or ponds. In many cases it is apparent that both erosion and aggradation are controlled by these minor features, and that the latter tend to become obliterated. These minor scarps, ridges, and sinks are not referable to any single earth-movement, but are referable to a recurrence of movement on the same general line. In the southern Coast Ranges the observations of Fairbanks show that one of these movements was of exceptional importance. By it displacements and disturbances of the surface were effected which dwarf all similar events in historic times. For miles at a stretch the earth, upon one side or the other of the fault line, sank, giving rise to basins and to cliffs 300 to 400 feet high. These features, in the opinion of Fairbanks, who personally examined them, were the result of one movement. This displacement probably occurred not less than 1,000 years ago. It is certainly older than the great trees growing upon the ridges and hollows formed by it. Since then it is probable that numerous displacements of less extent have taken place, but the geomorphic effects of the smaller movements have, in some considerable measure, been effaced. Since the settlement of the state, the strain in the earth's

crust has continued to manifest itself, and several slight movements have been observed by residents of the country. In 1857 there was a movement extending from San Benito County probably as far as San Bernardino Valley. The earthquake caused by this movement was not less severe than that of 1906, but we have unfortunately no measure of the extent or direction of the displacement. In this southern region described by Fairbanks, the displacements, even from the first, do not appear to have been of such a nature as to give rise to a continuous cliff or scarp upon either side of the fault; and this observation is generally true thruout the Rift. In one place the scarp faces southwest, in another northeast. In other places the vertical displacement has been very small and the scarps correspondingly insignificant. In several places, as, for example, at Fort Ross and between Mussel Rock and San Andreas Lake, displacements have occurred on subparallel lines, giving rise to opposing scarps, as if a wedge of ground, perhaps several hundred feet across, had dropt in. In such depressions lie the sinks; but the latter are more commonly formed by a low scarp facing up a slope, or by a ridge of surface compression formed across the path of the drainage from a slope. They have also been formed by landslides, which have shown little tendency to move save under seismic impulse.

It remains to call attention, in a word, to the alinement of the Rift with certain of the larger continental features. The Rift is known from Humboldt County to the north end of the Colorado Desert. As a line of small displacements it has not been traced farther; and in the usage of the term it has been understood as terminating at the point where it eluded field observation. But it is by no means certain that, as a larger feature, it does not extend far to the south. The Colorado Desert and its continuation in the Gulf of California are certainly diastrophic depressions, and may with much plausibility be regarded as a great Rift valley of even greater magnitude than the now famous African prototype first recognized by Suess. This great depression lies between the Peninsula of Lower California and the Mexican Plateau. All three of these features find their counterpart in southern Mexico. The Sierra Madre del Sur is the analogue of the peninsular ridge; it lies on the line of its prolongation, and is similarly constituted geologically. Inside of this range, and between it and the edge of the Mexican Plateau, is a pronounced valley system which is the analogue of the Gulf of California.

On this valley-line lies the deprest region about Salina Cruz, well known to be subject to repeated seismic disturbances. On the same general line lies Chilpancingo, the seat of the recent disastrous Mexican earthquake. Following these great structural lines southward, they take on a more and more latitudinal trend; and beyond Salina Cruz the geological structure indicates that this seismic belt crosses the state of Chiapas and Guatemala, to the Atlantic side of Central America with an east and west trend, and falls into alinement with Jamaica. It thus seems not improbable that the three great earthquakes of California, Chilpancingo, and Jamaica may be on the same seismic line which is known in California as the San Andreas Rift.

THE EARTH MOVEMENT ON THE FAULT OF APRIL 18, 1906.

THE FAULT-TRACE.

The successive movements which in the past have given rise to the peculiar geomorphic features of the Rift, either directly or by control of erosion, have with little question been attended in every case by an earthquake of greater or less violence. The earthquake of April 18, 1906, was due to a recurrence of movement along this line. The movement on that day was of the nature of a horizontal displacement on an approximately vertical fault plane or zone, whereby the country on the southwest side was moved to the northwest and the country on the northeast side to the southeast. This displacement was manifested at the surface by the dislocation and offsetting of fences, roads, dams, bridges, railways, tunnels, pipes, and other structures which crost the line of the fault. The surface of the ground was torn and heaved in furrow-like ridges. Where the surface consisted of grass sward, this was usually found to be traversed by a network of rupture lines diagonal in their orientation to the general trend of the fault. Small streams flowing transverse to the line of the fault had their trenches dislocated so that their waters became impounded. These and similar phenomena of disruption constitute the *fault-trace.*

The width of the zone of surface rupturing varied usually from a few feet up to 50 feet or more. Not uncommonly there were auxiliary cracks either branching from the main fault-trace obliquely for a few hundred feet or yards, or lying subparallel to it and not, so far as disturbance of the soil indicated, directly connected with it. Where these auxiliary cracks were features of the fault-trace, the zone of surface disturbance which included them frequently had a width of several hundred feet. The displacement appears thus not always to have been confined to a single line of rupture, but to have been distributed over a zone of varying width. Generally, however, the greater part of the dislocation within this zone was confined to the main line of rupture, usually marked by a narrow ridge of heaved and torn sod.

The amount of the horizontal displacement, as measured on dislocated fences, roads, etc., at numerous points along the fault-trace, was commonly from 8 to 15 feet. In some places it exceeded this and at one place it was as much as 21 feet. Toward the south end of the fault the amount of displacement was notably less and finally became inappreciable. Nearly all attempts at the measurement of the displacement were concerned with horizontal offsets on fences, roads, and other surface structures at the point of their intersection by the principal rupture plane, and ignore for the most part any displacement that may be distributed on either side of this in the zone of movement. The figures thus obtained may, therefore, in general be considered as representing a minimum for the amount of differential movement. In one or two cases, however, when the displacement has been measured on soft ground subject to slumping, and the measured offset is higher than usual, the results may be in excess of the true crustal displacement.

Besides this horizontal displacement of the crust, there was also, particularly in the region north of the Golden Gate, a distinct uplift of the country to the southwest of the Rift, relatively to that on the northeast. This differential vertical movement was made

manifest by the appearance of low, abrupt fault-scarps, ranging from less than a foot up to 3 feet. Many of these occurred along the slope of somewhat degraded fault-scarps due to former movements, and served to revivify them. In other cases the new scarps have been developed on slopes where no trace of a previous scarp can be detected. The low scarp which was formed on April 18 is by no means a continuous feature, but appears at a great many places not widely spaced along the fault-trace, extending often for hundreds of yards at a stretch, with intervals where no abrupt scarp can be detected. In the latter places it is probable that the differential vertical movement has been distributed over a zone of some width, underlain by formations in which the deeper seated fracture would be taken up by plastic deformation. The scarp almost invariably faces the northeast, but a few cases have been noted in which a fresh scarp on the fault-trace faced the southwest for a short distance. These will be mentioned more particularly in the detailed descriptions which follow. Associated with the fault-trace, it is quite common to find secondary or induced movements of the soil, particularly on steep slopes. These partake of the nature of landslides, and very commonly exhibit the characteristic landslide scarp. This is usually, however, easy to distinguish from the scarp on the fault proper, or on the auxiliary cracks, since it lacks evidence of horizontal displacement, and the broken sod is not traversed by diagonal, torsional cracks.

The differential displacement of the earth's crust above indicated occurred only on the northern portion of the Rift. South of San Juan, in Benito County, there is no indication along the Rift in the shape of rupture of the soil, or the dislocation of transverse structures, which points to the displacement of the underlying formations. It is not, however, to be certainly inferred from this that there was no deep-seated rupture south of that point. Many earthquakes are known which are referable to sudden slips in the earth's crust for which there is no corresponding rupture at the surface. It is probable that the slip, which is so manifest as a surface rupture to the north of San Juan, was continued as a subsurface movement for many miles south of that point.

North of San Juan the displacement on the fault-trace has been followed practically continuously to a point on the northern coast of California a little beyond Point Arena, a distance of 190 miles. At this point the fault-trace as a continuous feature passes out to sea, and the evidence of displacement is lost. At Shelter Cove, in southern Humboldt County, however, where as previously stated the Rift features appear again, evidence of displacement due to movement on April 18 is also found. The doubt as to whether the Rift in Humboldt County is continuous with that which leaves the coast near Point Arena, of course also applies to the question of the continuity of the rupture on the day of the earthquake. If we assume that the line of rupture is continuous thruout, then its full extent from San Juan to Telegraph Hill is about 270 miles.

Beginning with southern Humboldt County, a somewhat detailed account will now be given of the phenomena of the displacement which occurred on April 18, 1906.

HUMBOLDT COUNTY.

We are indebted to the observations of Mr. F. E. Matthes for our knowledge of the facts concerning the portion of the coast from Shelter Cove northward. The low headland north of Shelter Cove, known as Point Delgada, is traversed by several fissures trending roughly parallel with the general sweep of the coast and presenting essentially the same surface appearance as the fault fractures observed in Sonoma and Mendocino Counties. While it has been found impracticable to demonstrate by actual measurement the existence of a horizontal displacement along any of these new fissures — in the absence of fences or other objects of sufficiently defined outline — yet it has seemed warranted to regard them as true fault or shear fractures, to be classed in the same

category with those found farther south, merely on the strength of their superficial resemblance.

The effects of a horizontal shear on thick grass sod in open country, as observed in a number of localities along the zone of faulting in Sonoma and Mendocino Counties, are as follows: On fairly level ground, where conditions are simplest and no vertical movement is evident, the sod is torn and broken into irregular flakes, twisted out of place and often thrust up against or over each other. The surface is thus disturbed over a narrow belt, whose width apparently varies with the magnitude of the displacement. Along the main fault, where the throw amounts to 10 feet or more, a width of 5 or 6 feet is not uncommon; on the secondary fractures, where the throw does not exceed a foot, the belt is generally only a foot wide. Whatever the width of the belt, the sod within it, as well as the unconsolidated material underneath, appears loosened up and not compact. It consequently takes up more space than before it was disturbed, and the surface of the belt is therefore slightly raised above the level of the ground, from an inch to a foot or more, according to the magnitude of the disturbance. Within such a belt there is seldom, if ever, a well-defined, continuous, longitudinal crack, the toughness of the sod precluding a clean shear fracture. Rather, there is a marked predominance of diagonal fractures resulting from tensile stresses.

To sum up, a horizontal displacement produces and may therefore be recognized in grassy country by a fault-trace showing:

1. The disturbance of the sod over a narrow belt.
2. The generally raised surface of this belt.
3. The absence of a single continuous, longitudinal crack.
4. The tearing of the sod along numerous diagonal fractures.
5. The twisting and thrusting of sod flakes against and over each other.

It was mainly by the aid of these criteria that the fault lines in the vicinity of Shelter Cove were determined as fault or shear fractures, distinct from the innumerable cracks due to the settling of earth masses consequent upon the jar of the disturbance. In practically all of these the sod had been ruptured by mere tension, or tension accompanied by more or less vertical shearing. Furthermore, as will presently appear, the location of the fault fractures was in many instances facilitated by their association with the characteristic fault topography observed all along the line.

What appears to be the main fault-trace was first observed in the bottom of Wood Gulch, where it runs immediately along the wagon road for a hundred feet or more. It was thence traced south to its southern terminus on the beach of Shelter Cove, and then north across Humboldt Creek up Telegraph Hill. Subsequently several apparently detached lines of a similar character were discovered in the neighborhood of the main fault, as shown on the sketch map. Beginning at the south end, this line may be traced as follows:

On the beach of Shelter Cove, 100 yards west of the frame hut of Snider (at the mouth of Deadman Gulch), the fault passes thru the bluffs obscured by dislocated masses of dark conglomerates. From the top of the escarpment, however, it is easily traced for some distance down. The approximate contour map of the fault (fig. 10) sufficiently describes the topography here. A notable feature is a small elongated pond on the steep hillside, walled in by a small ridge. Thru this the fault-trace passes longitudinally. Continuing north, the line remains east of the upper valley of Wood Gulch until it joins the wagon road in the bottom. The line is by no means straight, as the bearings on the map indicate. A pronounced angle in its course exists at A (fig. 10), and the coincidence in this change of azimuth with the abrupt topographic change at this point is strongly suggestive of a hade to the west. Near the loop in the road at B the fault is easily recognized, except where the road has been repaired. The fault-trace here passes thru a

characteristic little gap or saddle (plate 31A), and south of *B* follows closely an old fault line, with a slight upthrow on the west. North of the road the fault-trace follows a ravine for some distance, then passes along the west side of a low ridge, as indicated in the contouring, and finally drops down to Humboldt Creek. Thence it ascends the south slope of Telegraph Hill, following for a considerable distance a characteristic fault feature on the steep brushy spurs indicated in plate 31D. Immediately south of the summit of Telegraph Hill the disturbance is the most pronounced, being accompanied apparently by an upthrow on the west side, resulting in a sharp-crested ridge some 4 feet high. It is possible, however, that this ridge is not the result of the recent disturbance, but of a former one, modified into a more acute form by the shaking off of the sod. (See plate 31c.) From the summit of Telegraph Hill a bearing was taken over the entire length of the line down to Shelter Cove: N. 25° W. Projecting the line north from the hill on the azimuth, it appears to head for a number of high mountains of the King's Peak Range, altho no visible traces of the disturbance are found north of Telegraph Hill. Immediately north of its crest is the upper end of a great hopper-like landslide, clean swept for over a thousand feet. The fault-trace is entirely obliterated by this slide. The exact location of the fault north of Telegraph Hill was not ascertained. Under the impression that it past close to King's Peak an ascent of this mountain was made, but without result.

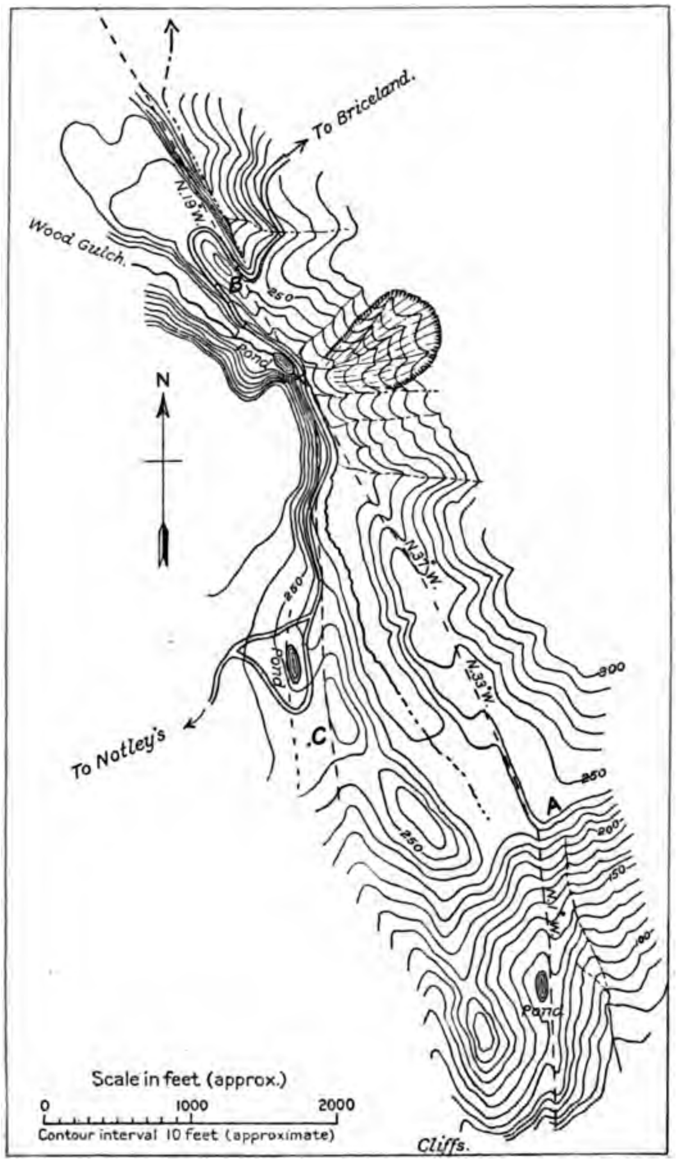


Fig. 10.—Map of country traversed by fault to north of Shelter Cove, Humboldt County.

Of the auxiliary cracks, the first one, *C* (see fig. 11), is a less pronounced disturbance than the main fault-trace, passing thru a depression bordered on its east side by a low scarp due to former faulting. A small pond encircled by the road lies on this fault-trace. Its bearing (not measured) is such as to make the line converge toward the main fault-trace and intersect the same in the vicinity of the pond in the bottom of Wood Gulch. The horizontal displacement along this line is probably small, much like that on the

A. Fault-scarp passing thru saddle at head of Wood Gulch, looking south-southeast. F. E. M.

B. Auxiliary fault-trace following old scarp in saddle between Wood Gulch and Humboldt Creek. F. E. M.

C. Looking south-southeast from Telegraph Hill along fault-trace marked by sharp-crested ridge in foreground, with upthrow of 4 ± feet. F. E. M.

D. Looking north-northwest along main fault marked by small ridges on spurs of Telegraph Hill. F. E. M.

auxiliary fault cracks accompanying the main fault-trace in Sonoma and Mendocino Counties, which it greatly resembles in surface characteristics. Another line of some prominence was discovered near the mouths of Humboldt Creek and Wood Gulch. As fig. 11 indicates, this fault-trace, *D*, follows for some distance along Wood Gulch, then crosses over to the little gorge of Humboldt Creek (plate 31B), which it follows out to its mouth. The divide at *D* has a marked depression along the line of faulting. The fence crossing it shows no signs of horizontal shifting. It was not learned whether or not it has been repaired since the quake. Tracing it to the south up over the grassy hills, it is found to disappear somewhere near the head of the little gulch shown on the map. A third line was found along the wagon road at *E*, following an old fault ridge descending the hillside on a slant. Its probable connection with the *C* line suggests itself.

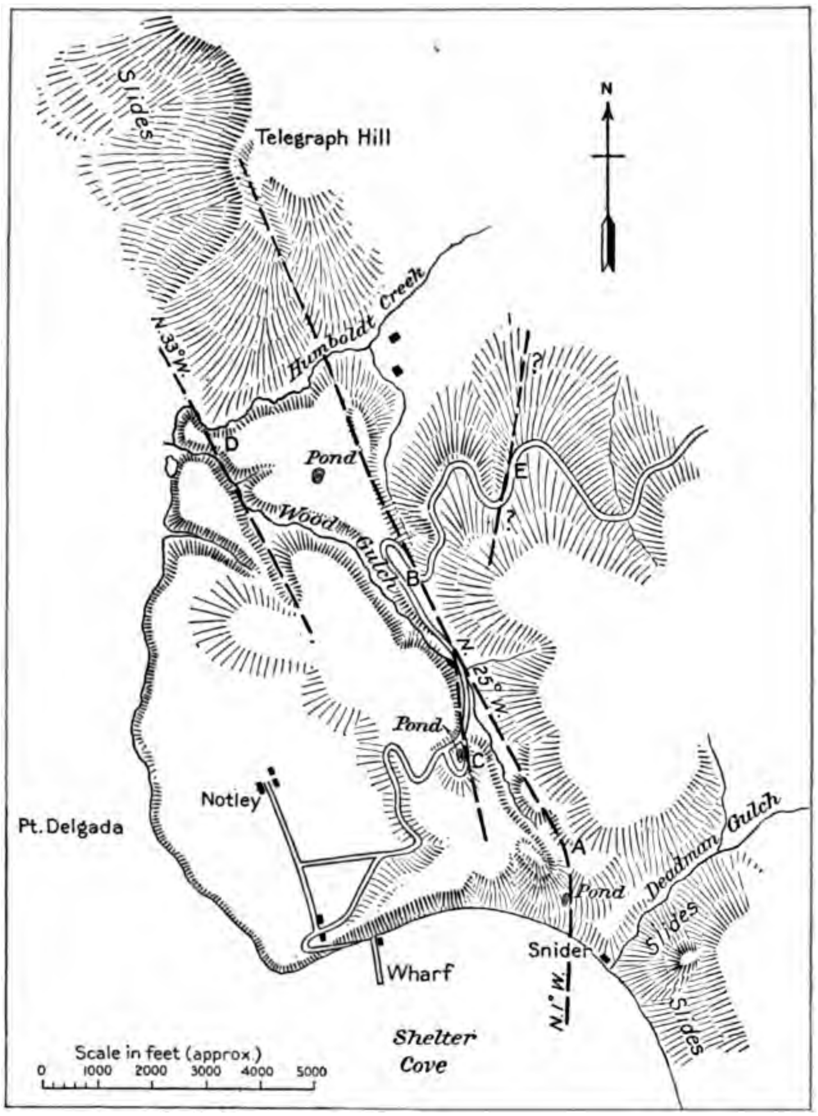


FIG. 11.—Map of country north of Shelter Cove, Humboldt County, showing auxiliary faults in relation to main fault.

In search of the north end of the fault, the following itinerary was made: From Telegraph Hill northeast to the old ridge road, to Albert Boots' ranch, thence up King's

Peak and its sister peak to the north; thence to Upper Mattole and Petrolia, *via* the stage road; from Petrolia north across the North Fork of the Mattole River, and along the same over the high terraces to the north branch of the North Fork; also westward over the hills, north of the river, to the summit of the last hill next to the coast, and back along the river; from Petrolia south to the bridge, and up the hills south of the town to the top of the great slide existing there; south to Cummings' ranch; and thence across Cooskie Range, between Squaw Creek, Spanish Creek, and Cooskie Creek. It was on the high bald spurs between Cooskie, Randall, and Spanish Creeks, close to the coast, that old Rift topography was for the first time encountered in this district. Several small ponds and ridges are found both on the spurs and close to their bases next to the beach. No sign, however, of a fresh disturbance could be found here.

Finally, an excursion up the coast to Cooskie Creek and then south along the beach to Shelter Cove served to encompass the entire area under investigation. A short side trip was made up the creek flowing from King's Peak, but nothing definite could be learned regarding the location of the fault. South from Hadley's ranch at Big Flat, the precipitous mountain slopes have been destroyed by extensive and high landslides, the dislocated materials of which have frequently advanced out upon the beach in the form of glacier-like tongues. The waves at high tide have since nipt these protruding masses and truncated them at their ends. Many of the slides occurred apparently on the sites of older ones. Their continuity and extent made the discovery of the fault in this neighborhood impracticable. The prevalence of great slides along the coast, back inland, seems to suggest the possibility of the fault curving along the coast, and gradually leaving it south of the Big Flat Ranch. In the belief that this might be the case, and that the fault might continue closely along the coast for some distance, to reënter farther north, a visit was made to the great slide at Cape Fortunas — the most extensive slide along the north coast. No trace of the fault could be discovered here, however. No visit was made to Cape Mendocino nor to Needle Rock, a small promontory south of Shelter Cove. As seen from the cove, this rock has a pronounced saddle suggestive of faulting. Should the fault-trace run thru it, it would have a very strongly curved course, parallel with the coast.

Mr. Matthes' account of the conditions in the vicinity of Shelter Cove may be supplemented by the following note by Professor A. S. Eakle:

Shelter Cove appears as a broad slope spreading out and forming a circular coast line of about 2 miles in length, with a flat plain 6 to 10 feet above the sea. The ocean is constantly wearing away the land and no beach surrounds it. Half a mile from the ocean the land begins to rise in grassy hills which are abruptly cut off from the high mountains behind by a deep canyon. The formation of the cove indicates that it has been broken off from the hills above by a huge landslide, perhaps by a former earthquake. The gorge which separates it from the mainland is on a line with the general coast. On the south side of the cove there are three parallel deep gorges which extend a short distance into the hills; and their continuation over the hills is shown by slight depressions which appear to have been clefts which have become almost filled with the wash of the hills. Along all these lines of weakness fissures were opened and the ground subsided 2 to 3 feet. Cross fissures running from one depression to another are also present. The trend of the main fissures followed the coast, which is northwest-southeast. On the high crests of the Cooskie and King Mountains, which border the coast north of the town, fissures and landslides were reported by ranchers looking for cattle, but this region was not visited. In the range south of the cove landslides were also reported and a photograph of a large one was taken. The rocks of the coast are sandstones and black shales, and the hills and plain of the cove were composed of blue and yellow sandy clay, evidently derived from the decomposition of the shales.

POINT ARENA TO FORT ROSS.

For the course of the fault and the phenomena of earth movement along it for the stretch of 43 miles between the mouth of Alder Creek and the point on the shore south of Fort Ross where it passes beneath the Pacific, we are again indebted to Mr. F. E. Matthes, who, on behalf of the Commission, made an examination of this territory. In the vicinity of Fort Ross, however, several observers contributed notes as to the phenomena there. For this entire distance, the rupture of the ground and its differential displacement are strongly marked and, except for the occasional local obscuration of the phenomena by brush and timber, are easily traced. The fault-trace enters the shore less than half a mile north of the mouth of Alder Creek and crosses with a course of S. 28° E. the bench-land, or wave-cut terrace, to the banks of the creek about 500 feet in from its mouth (fig. 12). Over the surface of the bench it is marked by characteristic rending and heaving of the sod. At the point where it reaches Alder Creek, the stream bank is rocky and steep, and the course of the crack can be traced down the rocky bluff, tho somewhat obscured by talus. The face of the bluff is shown in plate 32A. On the edge of the bench above the stream cliff (B, fig. 12), there is a rocky knob projecting above the general level. The earth crack passes close to the southwest side of this knob. The hade of the crack on the face of the bluff for a height of about 50 feet is very nearly vertical, but its deviation, if any, from the vertical could not be accurately measured on account of the ragged character of the bluff and the loose rock upon its face. On the northeast side of the rocky knob above referred to, there is evidence of a less well-marked parallel crack, as indicated on the sketch (fig. 12). This also appears on the rocky bluff of the stream cliff, but is less distinct than the main crack.

Southeast of this point, the fault-trace follows the broad stream bed of Alder Creek for nearly a mile, passing beneath a bridge, the wreck of which is shown in plate 32B. In this view, the horizontal offset of the bridge along the fault-line is well shown. It is apparent that this offset is not less than the width of the bridge. On the southwest side of the stream, near the bridge (A, fig. 12), the fault-trace is flanked by peculiar, isolated, rocky knobs similar to that on the northeast side. It is not clear, however, that these rocky knobs have more than an accidental relation to the fault, since they may possibly be residual sea-stacks upon the uplifted wave-cut terrace.

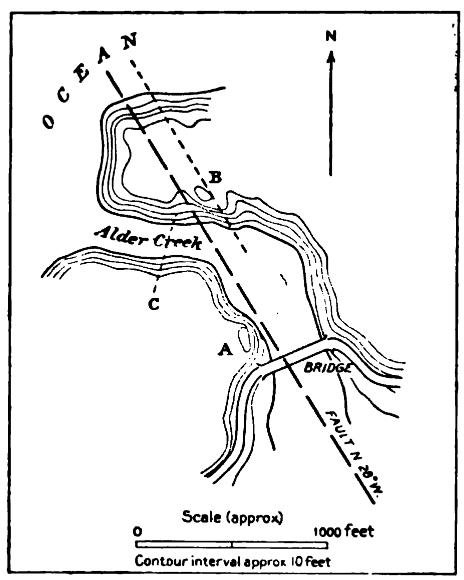


FIG. 12. — Map of mouth of Alder Creek, showing position of fault-trace.

After leaving Alder Creek, the phenomena of surface rupture and displacement were traced thru a series of ranches to the divide passing over to Brush Creek, and down to the vicinity of Manchester. Along nearly this entire distance between Alder Creek and Brush Creek, the line passes thru a series of depressions, swamps, and ponds, the majority of which are not connected with the neighboring streams. Offsets due to the displacement were measured on two fences of Mr. E. E. Fitch's ranch, and the amount of movement was found in each case to be 16 feet, the southwest side having moved relatively toward the northwest. The vertical displacement was, as a rule, quite small; only in a few places did it amount to a foot, presenting a low scarp of that height facing the northeast. To the north of Manchester, an east-west fence line was offset in three places,

the zone of dislocation being in low, marshy ground. At another place near Manchester, where an east and west fence follows the north side of a wagon road, both fence and road have been offset as shown in plate 32D. In both cases the relative movement on the southwest side was to the northwest. The dairy barn on the ranch of Mr. E. E. Fitch stood astride the line of movement and was demolished by the torsion to which it was subjected. The wreck of the barn is shown in plate 32C. At two places along the stretch between Alder and Brush Creeks the bearing of the fault-trace was measured, the readings being N. 28° W. and N. 30° W.

Southeasterly from Manchester the line of dislocation passes over the dividing ridge between Brush Creek and Garcia River, presenting the same general features. The upthrow is distinctly on the southwest side, but amounts, as a rule, to only a few inches. The horizontal displacement was measured on a line fence south of the divide. The fence is offset in two places. The principal displacement amounts to 13 feet; while on the minor offset, a little to the east, the displacement is 2.5 feet. The relative movement in both offsets is in the same direction, making the northwesterly displacement of the southwest side 15.5 feet. This fence is shown in plate 33A. South of this divide the main fissure passes thru a depression immediately east of a prominent knob projecting south from the divide; while a subordinate fissure traverses featureless hillsides from 100 to 150 feet farther east.

For some distance up the Garcia River from the point where the Rift intersects it, the line of dislocation traverses the flat alluvial bottom land, crossing and recrossing the stream bed. At David Jones' ranch it leaves the bottom and ascends obliquely the side of the valley; and from this point to its head waters it remains on the western side of the valley. Its path is thru a belt of ridges and swamps. Part of the way there are two sets of ridges, the lower or eastern of which coincide with the new line of rupture. Looking along the valley, the more prominent of these ridges appear as notable features of the transverse profile. Opposite Hutton's ranch, the line is found about 500 feet west of the river, and about 60 feet up on the valley slope. It crosses a road and fence here, producing offsets of 10 feet in both, in the same sense as before noted. At the head of the Garcia River, the fault-trace passes thru a low saddle into the valley of the Little North Fork of the Gualala River.

Down the Little North Fork, the fault-trace follows the axis of the valley on its west side; at a point 1.5 miles north of its junction with the North Fork it runs lengthwise for over 100 yards with the grade of an abandoned logging railroad, tearing the same to pieces. Interesting evidence of the condensation or shortening of the ground in this vicinity is afforded by the buckling of the rails as seen in plate 33D. Here the main line of dislocation lies about 100 feet to the east of the track in the stream bed. The effect of the movement was to shorten the steel rails either by buckling or telescoping after the snapping off of the fish plates. The small trestle in the distance is traversed at an acute angle by an auxiliary line of dislocation and is similarly shortened. At the locality shown in plate 33C, the buckling in the foreground resulted in the breaking of the rails. Similar instances of the shortening of the steel are shown in the distance. Here the main line of dislocation of the earth lies about 50 feet to the east of the track, and parallel with it. Plate 33B is a nearer view of the trestle above referred to. Below this point the fault-trace lies in the stream bed for some distance, crossing the North Fork at a point 200 feet east of its junction with the Little North Fork. Two lines of faulting appear here, both of which caused considerable damage to the railroad track; but the latter having been repaired before the date of Mr. Matthes' visit, no measurements of offsets were obtainable.

From this point southeasterly, evidence of dislocation along the line of the Rift, in its course up the valley of the South Fork of the Gualala, is obscured by the dense brush to

A. Rocky stream cliff 50 feet high on north side of Alder Creek. Fault vertical on left of knoll; auxiliary fault on right of knoll. F. E. M.

B. Fault passing under bridge over Alder Creek. Bridge displaced not less than its width. F. E. M.

C. Barn of E. E. Fitch, north of Manchester. Astride the fault. F. E. M.

D. East-west fence 0.25 mile north of Manchester offset by fault. Fence and road were formerly straight and have been repaired. Looking east. F. E. M.

A. East-west fence near saddle between Garcia River and Brush Creek. Main offset 13 feet. Auxiliary offset 2.5 feet in middle ground. F. E. M.

B. Small railway trestle, Little North Fork Gualala River, looking north. Main fault-trace 100 feet to right. Auxiliary crack under trestle. F. E. M.

C. Buckled track, Little North Fork Gualala River. Both rails broken. Fault-trace parallels track 50 feet to left. F. E. M.

D. Buckled track, Little North Fork Gualala River. Fault-trace 100 feet to left. F. E. M.

a point east of Stewart's Point. Here the line runs on the lower side of a double series of low ridges, interspaced with elongated swamps, and all trending parallel with the river. (See fig. 13.) Its bearing is N. 33° W., altho only short sights could be obtained on account of the timber and brush. The bearing noted is nearly in line with the axis of the valley of the South Fork of Gualala River. The amount of dislocation could be estimated only in a rough way from the offsets in the road leading east from Stewart's Point to Lancaster's ranch. A few neglected picket fences gave doubtful results, the alinement of the pickets having been previously disturbed by forest fires, fallen trees, etc. The horizontal movement is distributed over two strong, and one or more dim, lines of

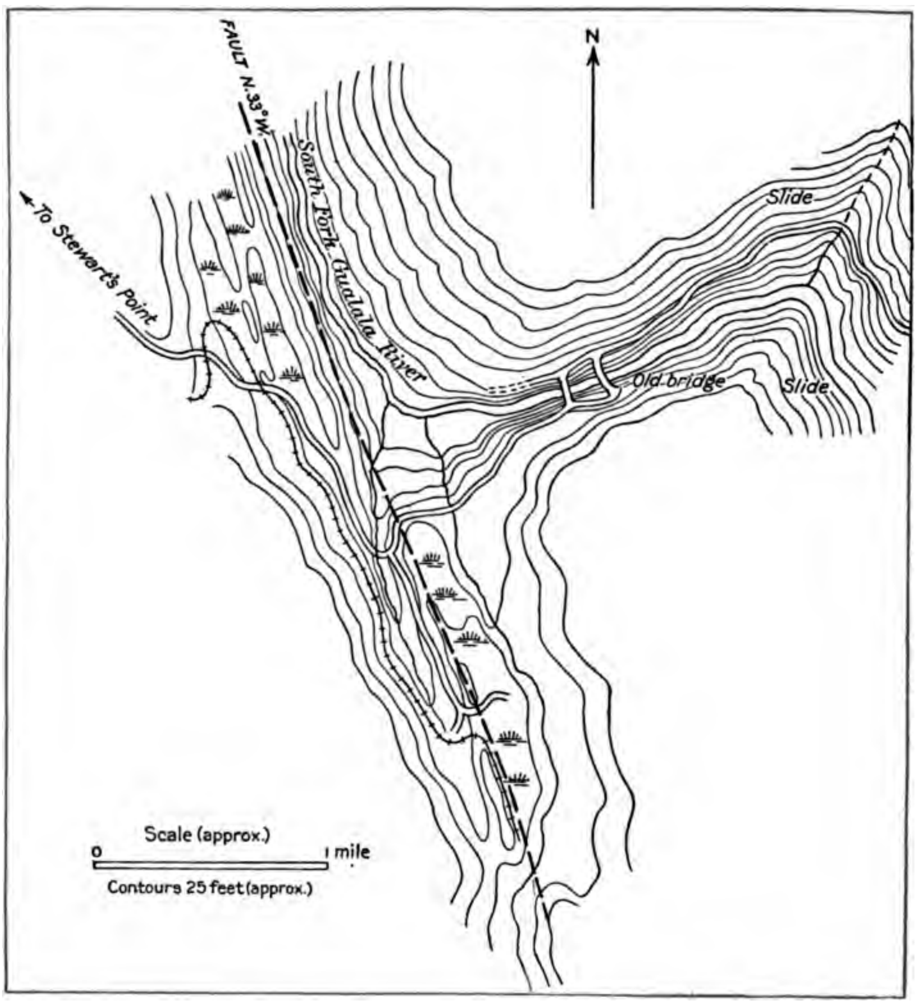


FIG. 13.—Map of valley of South Fork of Gualala River, showing relation of fault-trace to geomorphic features.

faulting, all of them producing offsets ranging from a few inches to several feet. The total displacement apparently did not reach 8 feet. As will be apparent from fig. 13, a logging road runs southeast parallel with the fault for 0.75 mile, and then crosses the same at an abrupt turn. It so happens that the road at this point has been cut thru one of the narrow ridges referred to, the depth of the cut being about 7 feet. The movement on the fault has practically closed the cut, so that it is now barely passable on foot. The bridge over the South Fork of the Gualala River, 3 miles east of Stewart's Point, had

its floor and end panels bent and the tension rods in the last two panels were buckled and twisted.

The upthrow on the fault east of Stewart's Point is on the west side; but farther up stream, where the fault runs along the steep west side of the valley below Casey's ranch, the upthrow is apparently on the east side. The foot trail from Casey's ranch to the river follows a marked longitudinal depression in the steep slope for 100 feet, and it is along the abrupt west side of the small ridge flanking the hollow (see fig. 14) that the fault-trace is located. The upthrow measures fully 2 feet, while the height of the ridge above the hollow varies from a few feet to more than 10 feet. The depression pitches to the north and is drained by a tiny brook. The fault-trace happens to coincide with the latter at a point where the trail crosses the watercourse over a rough wooden bridge. The horizontal movement along the fault practically destroyed the bridge. No measure of the displacement could be obtained here, but the indications are such as to warrant the belief that it did not amount to 15 feet, and that probably some of the horizontal shear had been distributed over minor lines of displacement higher up the slope and marked by landslides. These landslides above the depression in which the

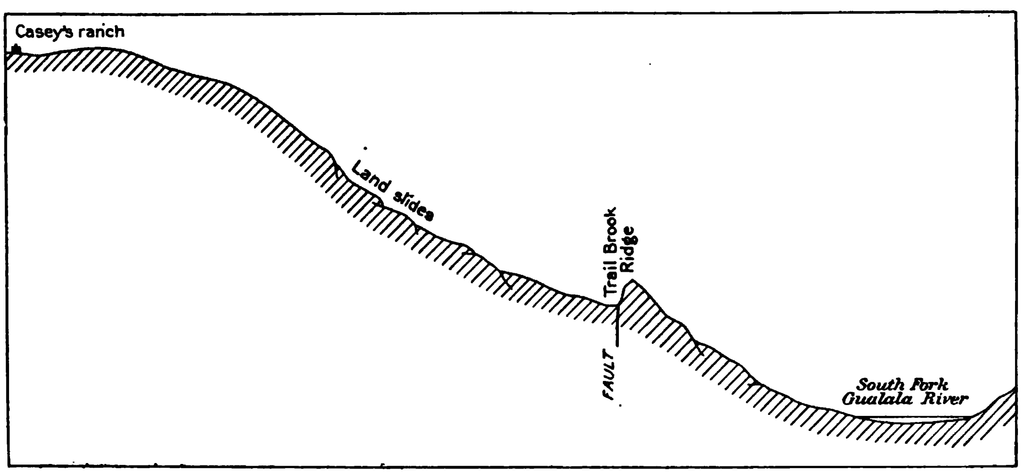


FIG. 14.—Profile of southwest side of South Fork of Gualala River, showing relation of fault to geomorphic features.

fault-trace lies are an important factor in the interpretation of the phenomena. It is easily possible that the scarp looking southwesterly over the depression referred to does not represent the real movement on the fault plane, but is a landslide effect. In any event, the proximity of the landslide weakens very much any judgment that might be formed, implying a reversal of the vertical movement which normally prevails along the line of the fault.

From Casey's ranch southeast, detailed observations were found to be impracticable owing to the dense tangle of brush and fallen timber. The ridge between the upper stretch of the river and the coast is crost by the fault-trace thru a swampy saddle above Plantation House, and the fault-trace traverses the swamp. Plantation House stands practically on the line of disturbance, about midway in a zone 270 feet wide traversed by six roughly parallel lines of rupture. The general bearing of the principal line was found to be N. 38° W. Southward the main fault passes thru a series of swampy hollows along an abandoned road, now impassable because of the cracks thru it. The line was traced south for 2 miles, its general appearance being found to remain the same thruout. There is a marked upthrow along its west side, not exceeding a foot at any place. Where

it crosses the stage road at the Plantation House, the vertical displacement on the main fault measured 6 inches; that on the secondary lines did not exceed an inch.

At Buttermore's ranch, about a mile east of Timber Cove, the displacement is distributed over three fissures, the principal one running 30 feet west of the dwelling. It intersects three fences, all of which show offsets of about 8 feet. The original crookedness of the fences and the repairs made since the earthquake make the accurate determination of the displacement impossible. The fault-trace was followed for some distance south and north from the ranch thru the forest, and found to follow the swampy depressions most of the way with low scarps or ridges to the west. The ranch and its fields lie for the most part in a broad swampy saddle. The upthrow in this neighborhood is on the west side, not exceeding 15 inches anywhere.

FORT ROSS.

North and south of Fort Ross, the phenomena of displacement are well displayed, both on the open-terraced coastal slope and in the timber. The rupture follows for the most part a single well-defined line in the path of the old Rift, coinciding in many places with ancient scarps and the slopes of low ridges. (See plates 35A and 36D.) The fault-trace is commonly marked by a ridge of heaved sod with diagonal cracks as illustrated in plates 35B and 36B. New scarps occur as shown in plates 36C, and 38A, B, as well as accentuations of old scarps. There are, however, several subparallel cracks. Two of these, having each a length of about 150 feet, lie to the west of the main line at a point 1,250 yards northwest of Doda's ranch-house, one 50 and the other 100 feet distant from the main crack and disposed *en échelon*. Within 300 yards to the southeast of this are two short cracks still closer to the main one, and springing from it, at about 450 yards northwest of Doda's ranch-house, is a parallel crack 440 feet in length and 60 feet from the main line. In this case the scarp appears upon the auxiliary crack, and not upon the main line of rupture. Between the short discontinuous crack and the main line is a swampy depression. On the southeast side of the ravine, southeast of Doda's house, the main crack is paralleled by two subordinate cracks, one on each side. That on the southwest side is about 250 feet long and 50 feet from the main line. It has a low scarp facing northeast, but not so pronounced as that on the main line of rupture. The crack on the northeast side of the main line has a length of about 1,125 feet and converges upon the latter toward the northeast. At its northwest end it is 190 feet from the main crack and at its southeast end only 50 feet distant. It has a low, discontinuous scarp facing northeast.

In a distance of 7,250 feet measured along the line of the fault, there are twelve stretches of scarp ranging in length from 125 feet to 1,000 feet, counted both on the main and on the auxiliary cracks and aggregating 3,000 feet in length. Of these eight face northeast and four southwest. The eight scarps facing northeast aggregate 2,250 feet in length, while the four facing southwest aggregate 750 feet. Two of the southwesterly facing scarps, however, aggregating 375 feet in length, are on the descent to the ravine southeast of Doda's house, where there is considerable sliding of the ground, and they may possibly be accounted for as secondary features due to landslides. The other two scarps facing the southwest are unexplained. They are abnormal and are so exceptional that they scarcely weaken the general conclusion that the vertical component of the movement on the fault was upward on the southwest side. The amount of this vertical movement in the vicinity of Fort Ross probably does not exceed 3 feet. In the first hasty examination of the ground, it appeared as if the amount of vertical movement might have been as much as 4 feet. This impression was due to the fact that in places preëxisting scarps were closely followed by the fault-trace, and a sufficiently careful discrimination was not made between the proportion of the scarp due to the new displacement, and that due to

earlier movements. A review of the facts indicates that the addition to the height of the old scarps and the total elevation of the new ones rarely, if at all, exceeded 3 feet. In general it was less than 2 feet.

The distribution of the line of faulting for a typical stretch of the Rift near Fort Ross, the auxiliary cracks, the disposition of the scarps upon these, and the relation of the whole to the old Rift features, are well shown on map No. 3 by Mr. F. E. Matthes. The horizontal displacement is also indicated on the map, but this needs more detailed statement.

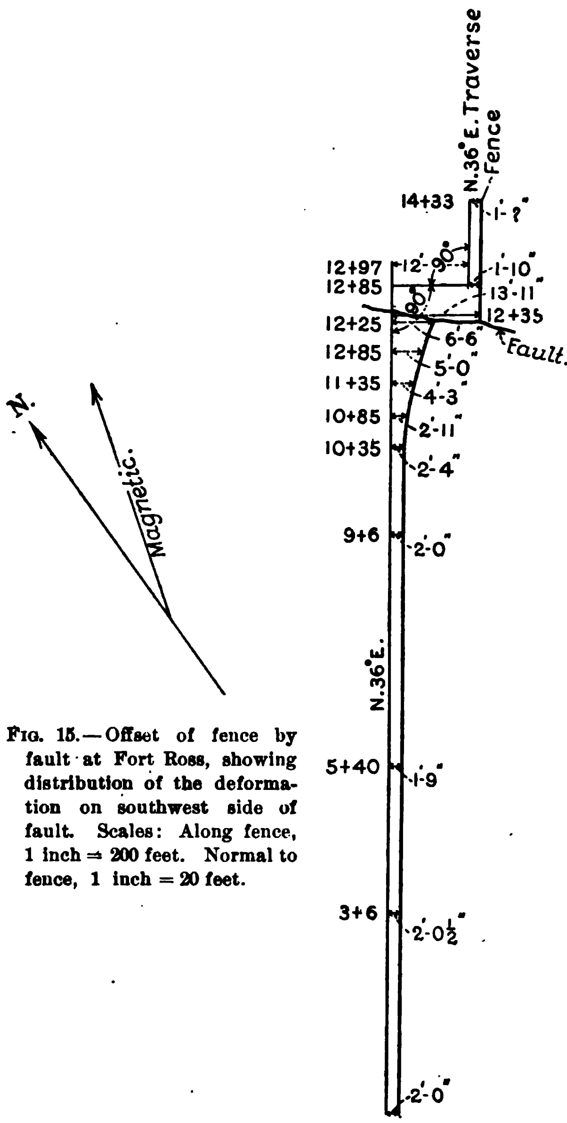


FIG. 15.—Offset of fence by fault at Fort Ross, showing distribution of the deformation on southwest side of fault. Scales: Along fence, 1 inch = 200 feet. Normal to fence, 1 inch = 20 feet.

On the line of the fault, about 300 yards northwest of the road from Sea View to Fort Ross, a steel water-pipe was dislocated by the earth movement, and found to be offset 8 feet, the southwest portion having moved northwesterly. This of course affords only a minimum measure of the relative movement. Where the road just mentioned intersects the fault-trace, both the road and the bordering fences were offset about 7.5 feet, with a slight sag on the northeast side. The zone of shearing here was from 10 to 20 feet wide. A wagon road on the Call ranch, south of the one above referred to, was offset 12 feet 3 inches, the line of dislocation being marked by an open fissure in the soil a few feet deep, and several short diagonal cracks, as shown in plate 36C. Another offset fence is shown in plate 36A, the displacement being here 8 feet at the fault-trace. The effects of the earth movement in the timber to the south of this are well shown in plate 34A. Several large trees standing on the fault line were split or torn asunder. The offset of the south line fence of the Call ranch was carefully surveyed by Mr. E. S. Larsen, and the results of his survey are shown in fig. 15. The bearing of the fence is N. 36° E. He reports that for the first 1,000 feet from the southwest end of the fence the greatest error in alinement was about 1 inch, and that practically there was no deformation in this stretch. In the next 125 feet going northeast there was found a deviation from this alinement of 4 inches to the southeast. In the next 50 feet the deviation in the same direction was 7 inches more. In the next 140 feet the deviation in the same direction was 3 feet 7 inches more. Then came the fault-trace with an abrupt displacement of the fence of 7 feet 5.1 inches. Northeast of the fault-trace the fence retained its line very well. In 100 feet it was out only 1 inch. Beyond this it enters the timber and its course is somewhat influenced by the larger trees, but maintains its line within a few inches. These measurements give a total horizontal displacement of 12 feet distrib-

A. Fault-trace in redwood forest near Fort Ross. J. N. L.

B. Dislocation of fence near Fort Ross. J. N. L.

A. Accentuation of old scarp by new fault 1.5 miles north of Fort Ross. J. N. L.

B. Fault-trace on grass-covered slope near Fort Ross. R. L. H.

A. Offset of 8 feet on fence a mile east of Fort Ross. R. S. H.

B. Fault-trace and dislocated fence near Fort Ross. R. S. H.

C. Roadway offset 12 feet. New fault-scarp 3 feet high, facing northeast. Above Fort Ross. F. E. M.

D. Accentuation of old fault-scarp by new fault. Near Fort Ross. F. E. M.

A. Offset of stream trench by the fault and ponding of water by the fault-scarp. Doda's ranch, a mile southeast of Fort Ross. A. C. L.

B. The fault-trace a mile northwest of Bolinas Lagoon, looking southwest. Illustrates the ridge phase. G. K. G.

uted over a zone 415 feet in width. Another fence farther southeast on Doda's ranch, having a bearing of N. 36° E., was offset on the fault-line 15 feet; the southwest side, as usual, having moved relatively to the northwest. This fence is shown in plate 34B. One of the most interesting effects of the displacement due to the fault is that seen where the latter intersects a small stream at Doda's ranch-house. The stream flows transversely to the line of the fault, and has a trench across the terrace about 5 feet deep. On the lower or southwest side of the fault, the stream trench has been moved northwesterly about 12 feet, so as to bring a fault-scarp across the entire width of the upper part of the trench and impound its waters in the form of a pool. The result is shown in plate 37A and also on Mr. Matthes' map of the Rift at this place (map No. 3). The impounding of the waters on the line of the fault is interesting evidence of the absence of any open crack.

BODEGA HEAD TO TOMALES BAY.

The location of the fault across the neck of land which connects Bodega Head with the mainland was determined by Prof. J. N. LeConte. He reports that on the south side of this neck the main earthquake fissure was found passing about 50 yards west of a house occupied by Mr. Johnson. It could be traced as a multitude of small cracks in the swampy land from the bay to the road, then as a well-defined fissure up the small depression west of the house for 200 yards to where it disappeared in the sand dunes. No trace of it could be detected in the sand dunes, which reach from this point entirely across the peninsula. Only one fence crosses the fissure and this had been repaired so that no measurement of the displacement was possible. The movement was evidently northward on the west side, as was shown by the direction in which the bushes were bent. The vertical movement was about 18 inches, the uplift being on the west side. The sand spit which closes the bay on the south was examined for evidence of movement, but nothing could be detected in the drifting sand.

At the mouth of Tomales Bay there are two points projecting westward from the east shore, and both of these, according to the observations of Prof .R. S. Holway, are crost by the fault-trace. The first is a long, flat sand-spit extending well across the mouth of the Bay just south of Dillon's. The line of the fault was still visible in the sand on June 11, 1906, in spite of the obliterating action of the wind and the recent rains. The line lies near the base of the spit and has a northwest-southeast course. On each side of the crack are crater-like depressions, some of them being double or overlapping. Mr. Keegan, the owner of Dillon's Beach, reported that these craterlets were numerous and distinct. In some instances a great deal of sand and water had been ejected. Others are reported on the southwest side of the fault-trace, from which the belt containing them extends some 70 feet. The craterlets vary in size up to 6 feet in diameter and it is reported that on the day after the earthquake the water which stood in them could not be bottomed by a fishing pole.

About 1.5 miles southeast of this spit is a promontory about 100 feet high projecting into the bay. Some 400 yards from the end of this promontory on top of the ridge is a line of depression with two or three small ponds. The main fault fissure here divides into two cracks, one each side of this depression, which is about 150 feet in width. Standing on this ridge, the line of the fault can be traced at low tide for nearly 1.5 miles across the bottom of the bay to the sand-spit to the northwest, its course in general being parallel to the axis of Tomales Bay. (See plate 38c.) The horizontal displacement where the fault crosses the promontory is about 8 feet, as determined by the line of tall grass at the edge of the little ponds, the westerly side having shifted to the northwest.

TOMALES BAY TO BOLINAS LAGOON.

By G. K. Gilbert.

The Fault-trace. — The trace traverses the zone of the Rift. Its general course is N. 35° W. and it nowhere departs more than a few hundred feet from the straight line connecting its extreme points. For considerable distances it is a single line of rupture; elsewhere it is divided into parts which separate and reunite; and in yet other portions it is composed of unconnected parts arranged *en échelon.* There are no vertical sections exhibiting hade, but the relation of the trace to sloping surfaces indicates that the fault-plane is approximately vertical.

For considerably more than half its length the surface expression is a ridge from 3 to 10 feet wide and ranging from a few inches to about 1.5 feet high. (See plates 37B and 40A.) The ground constituting the ridge is in fragments, loosely aggregated, so that there are considerable voids. Where pasture lands are crost the turf is torn into blocks, and these, in conjunction with the cracks which separate them, make up a pattern. This pattern is always irregular and sometimes gives no evidence of system, but usually its lines have a dominant direction, traversing the ridge obliquely, the northern ends of the cracks pointing toward the eastern boundary of the ridge, and the southern ends toward the western boundary. The cracks have resulted from stresses connected with the horizontal faulting, in which the southwest block moved northwest with reference to the northeast block. (See plate 39.)

In other places, and usually for short distances, the surface expression is a shallow trench (plates 40B and 46B), with ragged vertical sides from 2 to 5 or 6 feet apart, and occupied by loosely aggregated fragments of the ground, the pattern of the fragments and interstices being similar to that observed in the case of the ridges. This phase suggests that just below the surface the fault may be somewhat open, so that there has been an opportunity for fragments to drop into it.

In a third phase the ground is not notably elevated nor deprest but is traversed by a system of cracks obscurely parallel one to another and making an angle of about 45° with the general direction of the trace. Their orientation is such that they run nearly north and south. The cracks do not meet, but leave the intervening strips of ground in full connection with the undisturbed ground outside the trace. This phase occurs chiefly in wet alluvium.

There are a few spots where for short distances the surface expression is a simple straight fracture along which horizontal motion took place.

In the detailed descriptions which follow, the first three phases described above will be spoken of as the *ridge phase*, the *trench phase*, and the *echelon phase*.

The most southerly observation of the fault-trace was on the spit separating Bolinas Lagoon from the ocean. Near the west end of the spit its surface is covered by small dunes, and among these the trace was seen in its echelon phase. After a lapse of nine months the drifting of the sand had obliterated most of the cracks, but a few were still visible. Inside the spit lie a number of islands, the largest of which, Pepper Island, has a nucleus of sand (the vestige of an ancient spit), but superficially consists mainly of a fine tidal deposit. In the earlier field excursions the fault-trace was here overlookt, the echelon cracks by which it is represented being mistaken for secondary cracks, but at the present time (spring of 1907) it is easily traced, even from a distance, because the vegetation on the two sides of it has acquired different colors. Unfortunately the camera does not discriminate these colors. (Plate 41A.) The echelon phase here dominates, but the ground east of the trace is deprest about a foot, and this depression has so changed the relation of certain plants to the tides that they now find the conditions of life unfavorable and are dying out. This matter will be considered more fully in another connection.

A. Fault-trace in old depression marked by scarp 3 ± feet high, with auxiliary scarp above. Doda's ranch, a mile southeast of Fort Ross. Looking southwest. F. E. M.

B. Fault-trace marked by scarp 3 ± feet high on west side. Southeast of Fort Ross, looking southwest. F. E. M.

C. Fault-trace extending from cliff in foreground across tidal flats of Tomales Bay, near its mouth. R. S. H.

D. Fault-trace between garden and house, Skinner's ranch, near Olema. Before earthquake center lines of path and steps were coincident; afterwards offset was 15 feet 9 inches.

A. Branch of fault-trace in north part of Bolinas. Looking north-northwest. Illustrates diagonal cracks. G. K. G.

B. Branch of fault-trace, near Bondietti's ranch. Looking south. Illustrates diagonal cracks. G. K. G.

A. Fault-trace a mile northwest of Olema. Looking northwest. Illustrates ridge phase. G. K. G.

B. The fault-trace west of Olema. Looking southeast. Illustrates the trench phase. G. K. G.

A. Looking southeast on Pepper Island. In the foreground the fault-trace is central. It trends toward the distant +. G. K. G.

B. Looking north from hill west of Woodville. From buildings (Strain ranch) a large rift ridge runs northwest between 2 fault-sags. The western sag is followed by Pine Gulch Creek. Fault-trace runs from right of pond in foreground to left of buildings and follows sag for a mile, gradually crossing it. G. K. G.

In the U. S. Geological Survey map of this region the islands are not represented. In fig. 28 they are represented as they appear at half-tide, or, more strictly, the parts shown are those covered by vegetation. This figure also shows the corresponding part of the delta of Pine Gulch Creek. After crossing Pepper Island and a smaller island immediately adjacent, the fault-trace disappears under the water of the lagoon and it was next seen on the mainland of the southwest shore near the head of the lagoon. In the interval it probably crosses the delta of Pine Gulch Creek between the lines of high and low tide, but this tract was not examined until after the floods of March, 1907, which overspread it with alluvium. A disconnected group of cracks opening in the alluvial plain of the creek about 400 yards to the west (plate 39A) probably marked the position of a divergent branch of the fault. This line of disturbance crost the creek and road near the bridge in the northern settlement of Bolinas, trending approximately north and south and fading out in both directions.

The trend of the fault-trace on Pepper Island is about N. 34° W., and if continued would bring the trace to the shore at the head of the lagoon, but its actual position on the mainland is farther west, indicating that there is either a swerving or an offset in the part not seen. Near the shore the fault occasioned a number of landslides which obstructed the road until removed; and beyond the confusion occasioned by the landslides the trace consists of a number of subparallel cracks occupying a belt several yards in width. There is also a nearly parallel branch of the trace in a fault-sag lying a little farther west, but this could be followed only a short distance, and has since been largely obliterated by plowing. Mr. Nunes, who cultivated this sag, states that it once contained a pond or marsh, and this he had drained, but the water stood there again after the earthquake, showing that the earthquake had caused a depression of the bottom of the sag.

The diffused cracks on the main line soon gather into a narrow belt and descend into a narrow sag, containing the barn and other farm buildings of the Steele place. After following the sag for a short distance, the trace gradually rises on its eastern wall, crosses obliquely an intervening ridge, and enters a parallel sag toward the east. In this sag, which also is narrow, the trace intersects one of the roads leading from Bolinas to Woodville and immediately begins to ascend the narrow ridge bounding the sag on the east. Crossing this ridge obliquely, it skirts for 0.25 mile the western border of the much broader sag in which the water of Pine Gulch Creek gathers before it enters the canyon from which it is named. This wall it descends obliquely, and, just before reaching the bottom of the sag, intersects and offsets a line of eucalyptus trees marking a property and township boundary. The ridge phase dominates in this region (plate 37B), and near the line of eucalyptus trees the trace itself has a small offset to the west. (See fig. 18.)

Now for nearly half a mile the trace follows a valley-bottom, being divided on the way between two or three branches. The ridge phase obtains, but there are several places in flat alluvial ground where the ordinary group of cracks is replaced by a single crack with clean shear. On Mr. Strain's place two fences were crost which afforded measurement of horizontal displacement. Beyond them the fault-trace becomes once more single, and, after passing a group of very small ridges and sags, begins to climb the eastern wall of a larger sag, which here contains Pine Gulch Creek. (See plate 41B.) Along its line there soon develop a small sag and ridge constituting a sort of shelf or notch on the wall of the deeper sag (plate 42A), and in this small sag are several ponds. (Plates 10A, 54A, and 55A.) The sag first rises for a distance and then gradually descends. The fault-trace exhibits here in alternation the ridge and trench phases, and at many points there is an apparent vertical displacement with throw of 1 or 2 feet toward the northeast. (Plates 10B and 48B.) Near Bondietti's house the individuality of the sag is lost, and the fault-trace swerves somewhat to the east. A parallel trace develops west of it, and the two come together near Beisler's place. Northwest of Beisler's is a relatively high fault

ridge, and the fault-trace climbs the end of this, following a narrow groove or ascending sag. Here also are ponds. Farther on it passes to the east of the ridge crest and follows a side-hill sag similar to the one followed 2 miles farther south, except that it is on the eastern instead of the western face of the fault ridge. (Plates 8B and 9A.) The apparent vertical displacement is here in the opposite sense, the west side having apparently dropt, but the throw is small.

Thence the trace descends obliquely to the canyon of Olema Creek 150 feet below. Where the creek makes a decided bend toward the west the trace crosses it twice, and then follows near its west bank for several miles. Not far from the second crossing it is subject to a series of offsets, giving to the trace as a whole the same echelon character commonly observed in the arrangement of its details. It is noteworthy that where these offsets occur the trace swerves somewhat toward the right and the new line begins at the left, so that the arrangement is essentially a magnification of the arrangement of cracks in what I have called the echelon phase of the fault-trace. There is this difference, however, that the elements of the larger echelon make a comparatively small angle with the general course of the trace. At several points in this part of its course the trace follows steep slopes from which the timber has not been cleared. On these slopes, which face the northeast, its course sometimes coincides with that of a very narrow sag occupied by marshy ground. Elsewhere it crosses an upland to which a series of sags gives gentle undulation and here it touches or passes near a number of ponds. (Plate 43.) The route of the fault-trace in this region and thence north to Papermill Creek is shown by fig. 16, a compilation based on data from several sources, including a few original measurements.

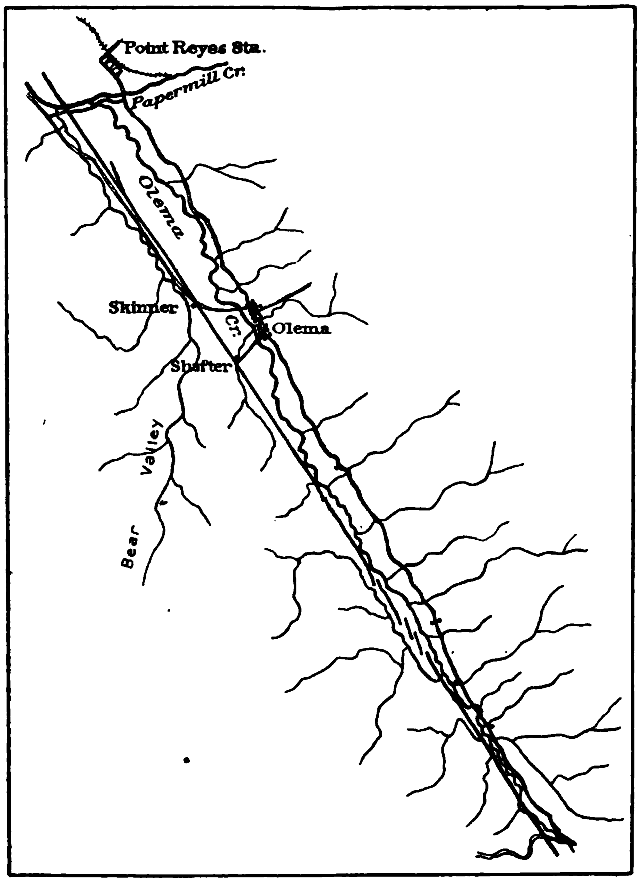


FIG. 16.—Map of fault-trace from Papermill Creek southward. Scale, 1:62,500.

A mile south of the village of Olema the trace enters a sag which is followed continuously for nearly 3 miles. At first the sag is narrow and is attached to the northeast slope of a ridge, but approaching the Shafter place the ridge crest sinks and a broad sag replaces it in the line of trend. (Plate 42B.) In following the eastern edge of this sag from the Shafter place to Papermill Creek the fault-trace also follows the western base of a line of hills. The hills are peculiar in that their western, or more strictly southwestern, base, being determined by faulting, is nearly straight (plate 42B); while their northeastern base, modified by the erosive action of Olema Creek, is scalloped. In this region the ridge phase of the fault-trace dominates, being occasionally replaced by the trench phase. (See

A. Sag followed by fault-trace a mile north of Strain ranch. Looking southeast. Trace, concealed by bushes, runs near ponds. G. K. G.

B. Looking southeast from point near Shafter's ranch, Olema. Fault-trace follows base of hill and includes water-filled depression. G. K. G.

A. Fault-trace 1.5 miles south of Olema. Looking southeast. Trace touches both ponds, being best seen between them. G. K. G.

B. Looking southeast across hill-top a mile south of Olema. Shallow sag gives hill double crest and makes a pond basin. The fault-trace, both in foreground and beyond, is divided in several branches. G. K. G.

A. Fault-trace a mile northwest of Olema. Looking northwest. G. K. G.

B. Fault-trace a mile northwest of Olema. Looking southeast. G. K. G.

A. Fault-trace on Papermill delta. Looking northwest. The water lanes are largely at right of main line of fracture. G. K. G.

B. Branch of fault-trace in "Second Valley," at Inverness. Looking south-southeast. G. K. G.

plate 44.) A few minor branches were seen on the east side. The pool or lane of water shown in plate 42B is about 2 feet deep. Mr. Shafter states that the ground here was dry and under cultivation before the earthquake. Shortly after the shock he noticed that the current of a creek close by was reversed.

Just south of the head of Tomales Bay, Papermill Creek enters the valley from the east, crosses to the southwest side of the valley and then turns toward the bay, in which it has built a delta. The delta occupies the whole width of the bay and is about 3 miles long, the greater part of it being submerged at high tide. At the head of the delta Olema Creek joins Papermill, bringing its tribute of detritus; and on the opposite side of the valley Papermill Creek receives the water of Bear Valley Creek, which brings no sediment but filters for some distance through a marsh. At the head of the delta a road crosses the valley, resting partly on the delta and partly on the marsh just mentioned, and furnished with an embankment to lift it above the floods. Just before reaching this road the fault-trace enters the marsh, where it quickly expands to a width of nearly 60 feet and exhibits the trench phase. Not only was the road offset by the fault and earthquake, but the portion between the walls of the trench was dropt down, the embankment sinking into the soft earth until nearly flush with the marsh. In restoring the embankment about 3.5 feet of earth were added. Close to the road Papermill Creek was crost, with offsetting of banks, and thence the fault was continued thru the delta to its end. (See plate 46A.) Its course is nearly straight and of such direction as to pass just outside the end of the cape near Millerton, the bearing being N. 35° W. At several points it is margined on the northeast by a lane of water (plate 45A), indicating that a narrow tract on that side is deprest, but no evidence was found of a general depression of land on one side of the fault as in Bolinas Lagoon. The echelon phase is dominant; the ridge phase does not appear. The trench phase obtains for short distances, and is combined for larger distances with the echelon. Where the trench phase occurs, it coincides with the zone of abundant cracks and is thus distinguished from the sag holding the lane of water.

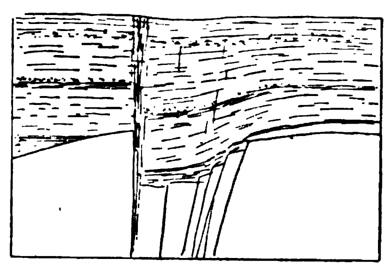


FIG. 17.—Hypothetic section of fault under Papermill Delta.

The general relation of the sag to the fault-trace is shown in fig. 17. It occurs only on the northeast side, but is so persistent that, from a commanding position, the fault can be traced out by means of the water lanes. The depression will probably average more than 50 feet wide, but it eludes measurement because it fades out gradually on the side away from the fault. The greatest noted depth is 17 inches, but the average is probably less than a foot. In attempting to interpret this feature I assume that beneath the smooth plane of the delta, and buried by its soft deposits, is a variegated topography of the rift type; and the hypothesis I advance is that the new-made sag on the delta plain is the surface echo of a fault-sag of the buried topography which was made deeper by the event of April, 1906. It has already been pointed out (page 67) that the sags of the Rift which were touched by the new fault were apparently deepened; and if the true explanation of the delta-sag has been suggested, we have in that feature an indication that the deepening was not only apparent but real.

At the northern edge of the Inverness settlement is an outlying or branch fault-trace about half a mile long. (Plates 45B and 47A.) Starting in what is called the "Second Valley," it ascends to a mesa and then descends toward the "Third Valley," its course being about N. 20° W. In crossing the upland it is associated with a fault-sag and there exhibits the trench phase with horizontal displacement of 2.5 feet. Two shorter traces, trending northward, occur on the slope between the "First Mesa" and the "Second Valley."

Measurements of throw. — At all points where horizontal throw was observed, the ground at the southwest, as compared to ground at the northeast, moved northwestward. On Pepper Island in Bolinas Lagoon a horizontal displacement was shown by jogs in the directions of the south coast, of the limit of vegetation at the north, and of a well-defined change of flora dependent on the relation of land levels to tide. These various features are too indefinite to give value to measurement of offset, but the general indication is that the amount of throw is somewhat larger on the island than at the nearest points of measurement on the mainland.

A mile northwest of the head of Bolinas Lagoon the fault-trace intersects a row of eucalyptus trees which had been set to mark a property line, the boundary between lands of S. S. Southworth and S. McCurdy. The row is now both dislocated and curved, and as there is reason to believe it was originally alined with care, its present condition shows the distortion of the ground at the time of the earthquake. The fault-trace, as shown by the accompanying map (fig. 18), is here offset *en échelon*, and the row of trees is not only crost by one section of the trace but approached by the other. At the point of crossing the dislocation is 10 feet. On the northwest side of the fault are six trees, all in line. On the southwest side are a dozen or more trees of which all but three are in line. If the line of either straight division be projected across the fault (broken lines in map) it passes 13.5 feet to the left of the line of the other division. The three trees nearest the

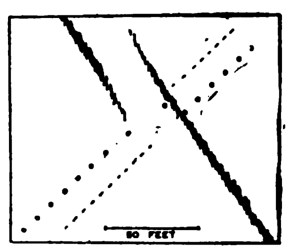


FIG. 18.—Dislocated row of eucalyptus trees.

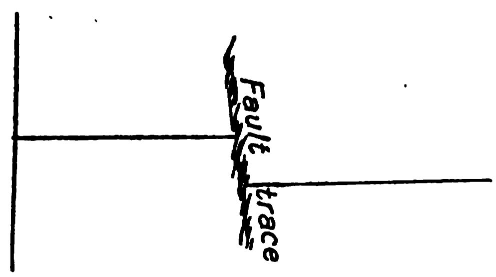


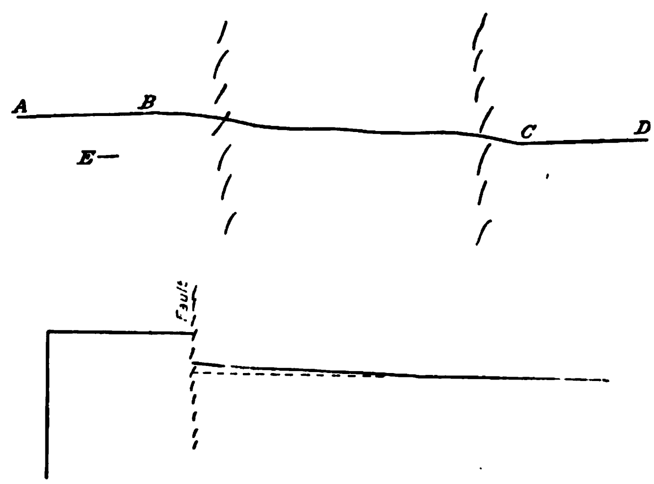
FIG. 19.—Dislocated fence on farm of S. S. Southworth, near Woodville.

fault on the southwest side follow a gently curving line. The indication is that about three-fourths of the whole displacement occurred on the main plane of the fracture, and the remainder was diffused thru the ground adjoining on the southwest. A closely related condition exists at the southern limit of the same field, where the fault-trace intersects a fence at right angles. The offset is 7 feet 8 inches, and this is accompanied by a change of direction. (Fig. 19.) Unfortunately the fence is too short to indicate in full the changes of the ground, but the suggestion is that in addition to the visible offset, there is a diffused shear affecting the ground southwest of the fault so that the entire displacement is greater than the amount shown by the offset. Assuming the fence to have been originally straight, the total displacement here was more than 12 feet.

On Mr. E. R. Strain's place, west of Woodville, measurements are afforded by the disturbance of two fences. The more southerly (fig. 20) is crost by two visible branches of the fault, and there is probably more or less diffused shear in the intervening ground. The fence, said by Mr. Strain to have been originally straight, has now two straight portions, *AB* and *CD*, and the distance from *AB* to *E*, on the line of *CD* produced, is 15 feet. The second fence, standing a little farther north, is intersected by one visible fault-trace, the continuation of the trace which crosses the first fence near *B*. On this line the fence is broken and offset 8.5 feet. The remnant of fence to the southwest is straight, but swerves in approaching the fault-trace, as indicated in fig. 21 and in plate 49A. The total displacement of the straight portions of the fence is about 11 feet.

The four localities last mentioned are included in the space of 0.5 mile. Their several indications of the total displacement, in the order of position from south to north, are 12 +, 13.5, 15, and 11 feet. The range of these determinations is 4 feet and their approximate mean 13 feet. At each locality the indicated displacement consists partly of definite faulting along one or two planes of fracture, and partly of diffused shear, distributed thru a belt of rock, or at least a belt of soil. At each locality the indicated shear is all in one direction. At each locality the measurement depends for its authority on the assumption that the disturbed fence or row of trees was originally straight.

Eight miles farther north, at Mr. W. D. Skinner's place, near Olema, the entire fault is apparently concentrated in a single narrow zone, and the several measurements made are in close accord. The fence south of his barn (fig. 22) was offset 15.5 feet. The barn, beneath which the fault-trace past, remained attached to the foundation on the southwest side, but was broken from it on the northwest side and dragged 16 feet. A path in the garden, originally opposite steps leading to the porch, was offset 15 feet. (Plate 38D.) A row of raspberry bushes in the garden was offset 14.5 feet. The mean of these four measurements is 15.25 feet, and their range is 1.5 feet.



FIGS. 20 and 21.—Dislocated fences on farm of E. R. Strain, near Woodville.

The road running southwest from Point Reyes Station and crossing the valley at the head of Papermill Creek delta was offset 20 feet. (Fig. 23 and plate 47B.) As the fault-trace at this point was between 50 and 60 feet wide, and as the embankment of the road for that distance was broken into several pieces, it was not possible to make certain that the dissevered remnants of the road had originally been in exact alinement. It is probable, however, that the road was approximately straight before the earthquake, and that the exceptionally great offset at this point is to be explained as the result of a horizontal shifting of the surface materials. The embankment of the road rested on marshy ground so soft that a portion of the embankment sank into it, and material of this character was in other localities demonstrably shifted.

A number of other measurements of displacement were made, but these, for various reasons, do not seem worthy of record, altho some of them were noted in an earlier report. Several were connected with the dislocation of trails, but in every such instance the trail made only a small angle with the strike of the fault and part of it was broken up along with the fractured turf. The endeavor to find more favorable angles of intersection drew attention to the fact that because the dominant trend of hills and valleys in the Rift is northwest-southeast, the lines of easy travel, minor as well as main, are largely parallel to the fault-trace. Other measurements were connected with the offset of fences, and, altho definite in themselves, have little value because there is reason to believe they represent only a part of the local displacement. The part represented by them is in every case less than 10 feet. It is noteworthy in this connection that most farm fences which were intersected by the fault-trace either terminated within a few yards of it or changed direction at about that place. Like the trails, they were adjusted to topographic peculiarities created by earlier faulting along the same line.

The phenomena of vertical displacement are in general so irregular as to indicate that they were determined chiefly by surface conditions. Where the ground sloped toward the northwest the horizontal throw caused an apparent vertical downthrow to the northeast. (Plate 48A.) Where the ground sloped toward the southeast an apparent vertical throw to the southwest was produced. Where the fault-trace followed a narrow sag interrupting the side slope of a ridge, the apparent vertical throw was on the side toward the ridge, as indicated in the diagram, fig. 6. (See also plates 10B and 48B.) The only unqualified record of vertical displacement is on Pepper Island in Bolinas Lagoon, where the mean of seven measurements shows a downthrow of 12 inches on the northeast side. The question whether the faulting along the plane of rupture was accompanied by the elevation or depression of large areas will be discust in another place.

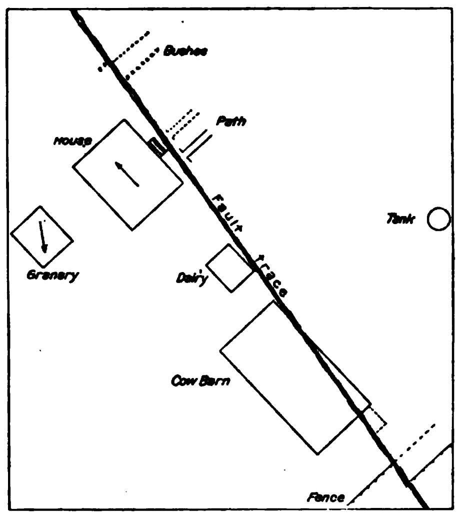


FIG. 22.—Plan of Skinner premises, showing character of displacements measured. The broken lines show positions of bushes, path, and fence before earthquake in relation to objects west of fault; also position before earthquake of corner of barn with reference to ground east of fault.

Movement normal to the fault-plane.—Where the fault-trace is a trench, imperfectly filled by fragments of soil and rock, it is clear that the walls of the fault stand farther apart than before the earthquake. Where the fault-trace has the echelon phase and consists of a system of cracks, not accompanied by visible elevation of the surface, it is also evident that the walls stand farther apart. Where the fault-trace is a ridge, composed of fragments of soil, with more or less interstitial void, it may be assumed that the voids are at least equivalent to the ridge in volume. As the fault-trace is made up almost wholly of these three phases, it follows that in the visible part of the fault its walls did not approach as a result of the faulting but receded a little.

In this connection mention may be made of the fact that at the Shafter ranch a fault crevice was momentarily so wide as to admit a cow, which fell in head first and was thus entombed. The closure which immediately followed left only the tail visible. At this point the fault-trace was a trench 6 or 8 feet wide, and the general level of the soil blocks within it was 1 or 2 feet below that of the adjacent undisturbed ground.

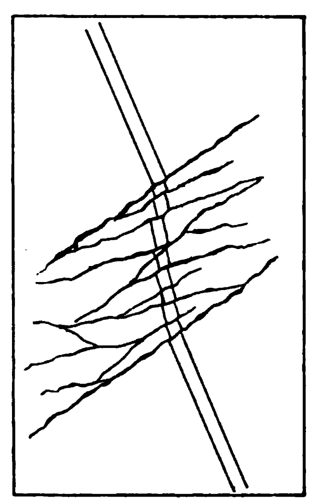


FIG. 23.—Dislocated road shown in plate 47B. Parallel lines represent wheel tracks. Ramifying lines indicate cracks of fault-zone.

One suggestion in connection with the recession of the fault walls near the surface of the ground is that temporary stresses incidental to the faulting caused permanent compression of the adjacent terranes. It is a fact familiar to engineers that most superficial formations, while in their natural, undisturbed condition, have a structure involving voids, and that they may be comprest by overpowering this structure. But, if I understand the matter, such formations are not compressible (except elastically) when their voids are full of water, so that accommodation for dilatation of the fault-zone could have been made in this way only so far as the ground was dry. As the ground was full of water in many places — including,

A. Fault-trace on Papermill delta. Looking northwest. G. K. G.

B. Fault-trace at the Skinner place, near Olema. Illustrating trench phase. G. K. G.

A. Branch of fault-trace on "north mesa" at Inverness. Looking southeast. G. K. G.

B. Road offset by fault. Looking southwest. G. K. G.

A. Fault-trace a mile northwest of Olema. Looking south. Appearance of vertical displacement largely due to combination of horizontal displacement with slope of ground. G. K. G.

B. Fault-trace near Bondietti's ranch. Looking southwest. Shows vertical displacement bordering a sag. Horizontal displacement shown by fence, which had been repaired. G. K. G.

A. Fence offset by fault. Looking northwest. Camera was alined with straight part of fence beyond the disturbance, to bring out flexure as well as offset of fence. G. K. G.

B. Cracks made by earthquake in tidal mud near head of Bolinas Lagoon. G. K. G.

for example, the locality of the cow incident, the Papermill delta, and Pepper Island — the suggestion of lateral compression seems of little avail.

Another suggestion is that the surface phenomena are essentially representative of what occurred at greater depths — that is, that in depth, as well as superficially, the faulting left the fault walls farther apart than they were before. Fissure veins show that voids have often resulted from subterranean faulting. Unless the surface along which the movement occurred is mathematically plane — or conforms to some equally difficult geometric condition — the two fault walls should not accurately fit together after the movement, but should tend to maintain contact thru only a part of their extent. If thru a part of their extent they are separated, the walls are on the average farther apart than before.

There would necessarily be some adjustment thru changes within the rock masses on the two sides of the fault. Compressive strains would be locally increased and reduced, and there would be subordinate movements among the minor earth blocks of the great shear zone whose surface features appear in the Rift. We have evidence of such adjustments, in fact, in branches of the fault-trace and in a system of bedrock cracks presently to be described; as well as in the subsidence of the bottoms of sags in the immediate vicinity of the fault. Interpreting other sag phenomena in the light of the long sag of the Papermill Creek delta, the fault of 1906 appears to have permitted a very considerable volume of material to sink into its fissure.

The general tendency of this discussion falls in line with a generalization as to the Rift, which in the Bolinas-Tomales region appears to show distinctly more local subsidence than local elevation.

Earlier fault-traces. — Because the future is to be judged by the past, there is much interest in the question of the frequency and recency of fault movements along the Rift previous to 1906. In my later studies of the Rift belt, I have had in mind the possibility of discovering fault-traces similar to that of 1906 but less fresh in appearance. In the little bluffs at the edges of sags, and in the ponds and marshes, there is abundant evidence of early faulting, but it is essentially geologic and does not necessarily pertain to occurrences of the past century or two. The fault-trace, however, is a relatively perishable and transient phenomenon, and its preservation might have comparatively definite meaning.

At two localities I thought I discovered old "traces" of the ridge type. In each case the features occur on a hill slope where the trace made in 1906 appears in several divisions or branches; and what I took to be old traces are distinguished chiefly by the absence of cracks. The localities are close together, about 0.5 mile south of the Shafter ranch, and may be identified by means of plate 43B. The features occur on the slope at the left, but are too indefinite to be recognized in the view. If these old traces have been properly identified, they are of very moderate antiquity. I should suppose that the ridges of the recent trace would lapse to such a condition in four or five years and that they might persist, under pasture conditions, for two or three decades. The history of the recent trace shows that a single plowing means effacement, but the general appearance of the field in which the old traces occur indicates that it was never plowed.

Cracks. — In preliminary reports I have classified the earthquake cracks as primary and secondary, the primary being occasioned by strains which existed before the earthquake, and the secondary being caused by the earthquake. With the multiplication of observations this classification has become increasingly difficult, and I now find it more convenient to group the cracks as superficial and deep, or superficial and bedrock.

Many of the superficial cracks are in alluvium. In the field excursions of April and May, 1906, they were seen in all alluvial formations within the Rift belt and for some distance on each side. The greater number appeared to be merely partings without

vertical or horizontal throw. In general they were not parallel with one another nor were they otherwise systematically arranged, except that some of them were apt to occur along the boundary between alluvium and a firmer formation. They were rambling rather than straight and were often branched. They ranged in width from a fraction of an inch to several inches. They were seen from the train in the bottom-land of Papermill Creek within a mile of Point Reyes Station. They were also seen in the delta of Papermill Creek, in the bottom-land of Olema Creek near Olema, and in the delta of Pine Gulch Creek. They were seen in the bottom-lands and deltas of a number of small creeks entering Tomales Bay from the west between Inverness and the head of the bay. Other localities were tidal marshes at the head of Bolinas Lagoon (plate 49B), at the head of Tomales Bay, and in small estuaries near Inverness. They were seen in the marsh of Bear Valley Creek near where the stream joins Papermill Creek; and a road embankment crossing that marsh was elaborately cracked and faulted thru much of its extent.

It is noteworthy that the neighboring road crossing a marshy portion of the Papermill delta was much less cracked, and the difference is probably to be ascribed to the difference in height and strength of the two embankments. The thinner one suffered the more.

The localities enumerated are merely those which came under observation. Within the zone of high intensity no marshes and no bottom lands were seen which did not exhibit cracks, and I regard their cracking as a general phenomenon. The elaborate cracking of a roadway across one of the marshes seems specially significant. In the adjacent soft marsh close attention was necessary to discover cracks. To a large extent they were concealed by the vegetation, and it is probable also that many which were opened during the earthquake agitation immediately closed again and were practically obliterated by the welding of the mud. But the road embankment, being free from vegetation and composed of comparatively rigid and brittle material, retained all the cracks made during the agitation, and thus served to record the thoro shattering of an unconsolidated formation when subjected to strong vibration. (Plate 50.)

Another class of superficial cracks affected hillsides, penetrating only the coating of loose material — decomposed rock and talus. The conspicuous individuals of this type are those that follow contours. Along these there was often a notable width of crack, accompanied by a settling on the down-hill side, and many cracks of this type are still visible. They are in effect the heads of incipient landslides and might with equal propriety be described under another caption. They are numerous thruout the Rift belt and fairly abundant on steep hillsides for more than a mile to the west. East of the Rift they are inconspicuous and believed to be rare. Some of the best examples are on the northeastern slope of Mount Whittenberg, about a mile from the fault-trace, the locality being favorable for observation because of the absence of forest.

Superficial cracks of a third type are connected with side-hill roads. (See plate 51.) In such roads there is usually a notch cut in the hillside and the excavated material is thrown outward so as to make an embankment. The roadbed thus consists in part of the natural formation and in part of an artificial and relatively loose embankment. In the loose material, and frequently along the line separating it from the firmer ground, cracks were extensively developed, often accompanied by evident settling of the outer bank. Their magnitude depended in part on the character of the material, but in large part also on the intensity of the earthquake. Where they were of such magnitude as to injure the roadway they were soon obliterated by road repairers, and elsewhere they tended to disappear in consequence of the traffic; but while they lasted they constituted an excellent gage of intensity, and much use was made of them in districts where there were few buildings.

Bedrock cracks occurred at many points within the Rift, usually appearing as branches from the faults. They were seen also at a number of points west of the Rift, their distribution reaching to the ocean in the vicinity of Point Reyes, ten miles from the fault-trace. At the more remote points they were quite small, often barely discernible, and no system of arrangement was discovered. They are peculiarly prominent along the summit of the ridge constituting the southwestern rim of the main Bolinas-Tomales trough. This summit was visited on four lines of road, and at each locality conspicuous cracks were found. On the road from Inverness to Point Reyes Post Office, about a mile in a direct line from Tomales Bay, a crack was traced for more than 800 feet. Its general trend is east and west, but its course is not straight and it has a branch diverging at 45°. Along this crack there is a horizontal throw of from 2 to 6 inches, the south side having moved westward with reference to the north side.

On the next road to the southward a group of cracks was seen at a point a mile from the shore of Tomales Bay. These cracks occur on a crest trending northwest and southeast, and their trend makes a small angle with that of the crest. The arrangement of the cracks suggests horizontal shear, but no definite observation was made on this point. They extend for several hundred feet at least, but were not traced out.

On Mount Whittenberg there are two bedrock cracks. One of these crosses the northeastern spur of the peak near its junction with the main crest. Its trend is approximately northwest and southeast and at one point it margins a fault-sag. As it assumes in one place the ridge phase of the fault-crop, I infer that it has horizontal displacement. On the opposite side of the main crest is a crack which was traced for about 1,000 feet. Its general course is northwest-southeast, but it is not straight and exhibits a vertical throw of 1 or 2 feet to the southwest. At one point it touches a fault-sag. Between these two long cracks a group of short cracks occurred, with similar trend, on a knob constituting a portion of the main divide.

About 6 miles farther south, at the head of Pine Gulch Creek, another road crosses the range, and in following this a group of cracks was seen. A short distance west of the divide, and about a mile in a direct line from the fault-trace, is a fault-sag trending northwest-southeast. On each side of it a crack was seen, the eastern crack being the wider and showing a small throw to the southwest. This crack was traced for about 0.75 mile and found to curve thru an arc of nearly 90° from southeast to southwest. At its southwest end, or at least the southwestern limit of tracing, it is on a ridge, and it there expands into, or else is replaced by, a group of cracks diverging fan-wise. On each member of the group faulting took place, the downthrow being toward the northwest except in the case of two apparently short cracks with downthrow to the southeast. On four of these cracks the throw was greater than 1 foot, and at one place it was about 5 feet. Each crack was associated with a preëxistent bluff or scarp, indicating that earlier movements have occurred at the same place. The field in which the principal phenomena occur is cultivated with the exception of the steeper scarps, whose faces retain a bushy growth. (See plates 52A and 53A.)

A tract lying between this locality and the coast, and extending several miles in each direction, exhibits a peculiar topography intermediate in type between that of the Rift and that commonly associated with landslides. Near the coast are a number of basins with ponds or lakes of much larger size than those along the Rift, and in association with these are seen a number of sags similar to the fault sags of the Rift. On several lines which were thought from the physiography to represent partings between dislocated blocks, earthquake cracks were seen, and on one of these near the coast there was a vertical displacement of 3 feet, the downthrow being to the southwest.

All thru the Rift there is association of earthquake cracks with fault-sags; probably half of the sags were bordered by such cracks on one side or the other, the crack usually

following the line of separation between the side slope and bottom slope. In some instances there was a crack on each side of the sag, but more frequently on one side only. Where the sag contained a pond the crack was usually present. With little or no exception these cracks exhibit downthrow on the side toward the sag. (See plate 52B.) At least two explanations of these cracks are possible. As the bottom of the sag usually shows no outcrop of rock and appears to consist wholly of soil washt down from the sides, it is possible that the earthquake caused a settling of the alluvium toward the middle of the sag and that the marginal crack is due to this settling. On the other hand, it is possible that a bedrock wedge underlying the sag was permitted to settle during the earthquake and that such settling caused the marginal crack. In the first case the cracks would belong to the superficial class; in the second, to the bedrock class. While the data at hand are not decisive, I am of opinion (as already stated) that the cracks resulted from some sort of readjustment of the small earth blocks whose upper surfaces determine the Rift topography.

Springs. — The general testimony of residents is that the flow of springs was modified all thru the peninsula west of the Rift. As it was practically impossible to get quantitative data, I made few records of specific instances, but every farm owner or farm tenant of that region with whom I talked told me of some spring whose flow had been increased, diminished, or stopt at the time of the earthquake, the change being either temporary or permanent. Several lakes of the group near the coast (known as Seven Lakes) experienced changes, the greater number having their levels lowered. A pond known as Mud Lake, on the divide at the head of Pine Gulch Creek and about a mile from the fault-trace, suddenly and permanently lost its water at the time of the earthquake. At the same time a small spring on the east side of the ridge and about 0.75 mile in a direct line from the pond, was suddenly enlarged, a torrent of water gushing from it for several hours and then gradually diminishing. It is suggested with much plausibility by residents that these two phenomena were connected, the earthquake opening a subterranean course thru which the water of the pond was conveyed to the hillside spring. I heard of no changes in springs east of the fault-trace, altho a number of inquiries were made.

Interpretation of bedrock cracks and springs. — The changes in springs are of course the results of changes in the conditions of underground circulation, and in a general way may be ascribed to the influence of newly-formed cracks. The spring phenomena and the visible cracks may be grouped together as indications of bedrock fracturing, and their distribution indicates the regions in which the rocky foundation of the land was more or less shattered. That region includes the Rift and extends from it to the ocean. The phenomena diminish somewhat with distance from the Rift, but the fracturing appears to have been important and general thru a belt 4 or 5 miles broad.

Landslides. — The earthquake started a number of landslides. A few of these were on the line of the fault, especially where its trace intersected a cliff facing Bolinas Lagoon. Others were from cliffs of earth or weak rock bordering the ocean, one of the bays, or a creek. None were seen of unusual type or of great importance, except from the obstructions to roads which they occasioned. South of Willow Camp a road overlooking the sea had been cut in the face of previous landslides, and the renewed movement put it out of commission. In the same manner roadways were obstructed at the entrance to Bolinas Lagoon, at two points near the head of the lagoon on the west side, and on the coast of Tomales Bay at Inverness.

There were many landslides of the dry type on hillsides, masses of earth and rock breaking away on steep slopes and tumbling to the bottom. The largest seen were on the high ridge west of Tomales Bay, in the vicinity of Sunshine Ranch. Closely related to these were small falls of earth and rock from the low cliffs created in the construction of side-hill roads. (Plate 53B.) They occurred at a few places within the Rift and

A. Road embankment broken by shaking of soft ground beneath. Southwest of Point Reyes Station and 10 rods from fault-trace. G. K. G.

B. Faults in road embankment, southwest of Point Reyes Station. Fault-trace is beyond fence. Ground lurched toward marsh of Bear Valley Creek. G. K. G.

A. Roadside crack 2 miles west of fault, between Inverness and Point Reyes P. O. G. K. G.

B. Roadside crack a mile southeast of Inverness. G. K. G.

A. Group of earthquake cracks southwest of head of Pine Gulch Creek. Looking southwest. Structure well indicated by sky line. Since dislocation field has been plowed and farm road graded up fault-scarps. Compare Plate 53 A. G. K. G.

B. Earthquake cracks in Bolinas at edge of an earthquake sag. G. K. G.

A. Fault-scarp on earthquake crack. Throw is about 5 feet. Compare Plate 52 A. G. K. G.

B. Landslide from road-cliff about two miles west of Inverness. Slide occurred at time of earthquake. G. K. G.

east of it, but mostly in the district to the west, where all of the country roads were more or less obstructed.

On the west side of the main ridge west of the head of Tomales Bay there occurred two wet slides. In one case a hillside bog was loosened from the slope on which it rested and descended as a flow of mud to a canyon bottom 100 or 200 feet below. In the other case the earth beneath a wet meadow in a rather steep canyon flowed down the canyon for about 0.5 mile, overpowering trees on its way and leaving a deposit 15 or 20 feet deep in places. This was the largest individual slide observed.

In all the cases mentioned the conditions were such that slides would have taken place at some time had the earthquake not occurred. But this statement may not properly apply to the cases about to be mentioned.

On the steep southern face of Mount Tamalpais a number of rocks were loosened and rolled down the slope, some of them being large enough to cut swaths thru the thicket which were visible for months afterward. Similar swaths were seen under a crag in the vicinity of Willow Camp. In the bottom-lands of creeks it happened at many places that a slice of the alluvium was separated by a crack parallel to the bank and slid into or toward the stream. In some cases alluvium lying with a gentle slope adjacent to a marsh slid toward the marsh, opening a crack along its upper edge.

Mention has already been made of numerous hillside cracks which marked incipient landslides. In such cases the downward motion apparently began during the earthquake agitation, but the momentum acquired was not sufficient to continue the motion after the earthquake stopt. In a very large number of these localities motion was resumed and landslides occurred during a period of excessive rainfall in the spring of 1907. (Plates 54A and 55A.) So far as my observation goes, all of the landslides having this history were wet, the material usually flowing freely down the slope as a thin mud. The probable explanation is that the cracks made in April, 1906, served to admit the water flowing over the surface during the rains of 1907, so that the material which was too dry to flow in 1906 acquired the proper consistency and continued its course the following year. The number of landslides which the earthquake induced in this indirect way is possibly as large as the number which were an immediate consequence of the shock.

The phenomena of landslides bring to attention certain conditions of flow which affect a variety of earthquake features. Consolidated formations hold steep slopes by virtue of cohesion. Incoherent formations maintain the "slope of repose" — 30° to 35° — by virtue of the resistance to sliding, or the static friction, of their particles. Certain formations, including some clays and clay mixtures, become coherent by drying and incoherent by wetting. Incoherent formations, as a rule, have a less coefficient of friction when wet than when dry. For these reasons the addition of water is the ordinary immediate cause of a landslide; it overcomes cohesion, or else it reduces the frictional resistance, and slipping or flowing is the result. During a strong earthquake, agitation overcomes the cohesion of feebly-coherent formations and suspends the operation of static friction between the particles of incoherent formations, thus affecting the materials somewhat as water affects them. In the case of landslides, it may enable an incoherent dry formation to flow as if wet; and it may temporarily give to an incoherent formation, wet or dry, a condition of quasi-liquidity.

Ridging and shifting of tide lands. — The general width of Tomales Bay near its head is about a mile, tho it is constricted at one point by a promontory jutting out from the east shore. (Fig. 24.) Papermill Creek, entering at its head, has built a delta which slopes so gently toward the deeper water that the tides range over it for a distance of about 3 miles. The upper half of the slope is covered by vegetation of various kinds and the lower half is of bare mud. In the region of vegetation the soil has sand as well as mud, and the bed of the stream is of sand and gravel. As the delta deposit has been

built up in connection with a shifting of the stream channel, or channels, it is probably composed of an irregular alternation of mud, sand, and gravel. The fault-trace, as already described, passes thru the midst of the tide lands, following the axis of the depression which contains the bay. Continuous with the mud of the lower slope of the delta is a mud shoal following the western shore of the bay past Inverness. This shoal and other parts of the tide lands were seen soon after the earthquake from the road which follows the west shore of the bay to Inverness, and a few photographs were made. Other photographs were made at various dates afterwards, and the tide lands were explored on foot on April 18, 1907.

A large portion of the delta was thrown by the earthquake into gentle undulations, the difference in height between the swells and hollows being usually less than a foot.

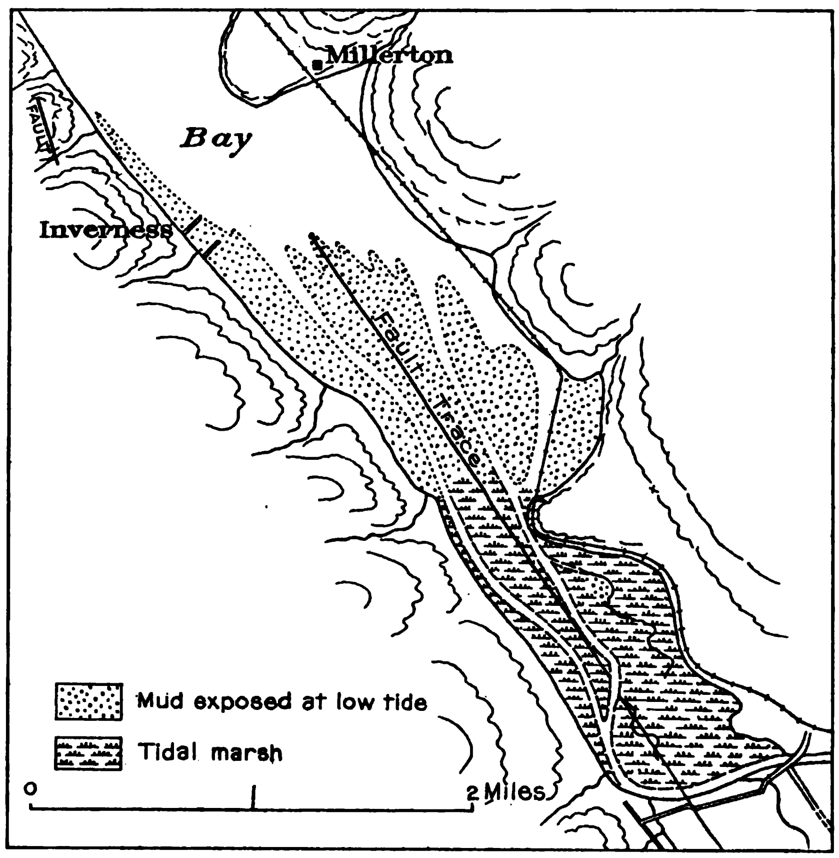


FIG. 24. — Map of Papermill Delta at head of Tomales Bay.

The chief evidence of this is found in the distribution of pools at low tide, and where vegetation is present the evidence from pools is supplemented by that from the condition of the plants. The undulations were not elongate and were not found to have a systematic relation to the fault.

When the tidal mud was first seen after the earthquake, it was observed to be covered with ridges and troughs. (Plate 54B.) This corrugation was gradually smoothed out by the action of the waves (plates 55B and 56A), so that at the expiration of a year its expression was largely lost, tho a few of the larger ridges could still be traced, and much of the plain retained a pattern imprest on it by the ridging. It is probable that the entire tract of tidal mud was thus affected, altho the ridges were not seen on the area lying nearest to the east shore. That area did not come under observation until after the spring floods

A. Landslide 4 miles northwest of Bolinas Lagoon. Looking south-southwest. Slide encroaches upon a rift pond, caused directly by rains early in 1907, indirectly by earthquake of 1906. G. K. G.

B. Ridged mud plain 1 mile from Inverness. Looking east-southeast. Mr. Hamilton's barn at right. April 28, 1906. Tide is low. Pools occupy the deeper troughs. G. K. G.

A. Landslides 2.5 miles northwest of Bolinas Lagoon. Looking northeast. Storm waters of 1907, guided by earthquake cracks, converted earth into soft mud. G. K. G.

B. South part of Inverness shoal, at low tide, April 28, 1906. Looking north-northwest. Lane of water separates firm, gravelly beach from mud shifted shoreward by earthquake. G. K. G.

A. Ridges caused by earthquake on tidal flat of Tomales Bay, 1 mile south of Inverness. Looking north. December, 1906. G. K. G.

B. Bed-rock shoal near Bolinas, with clam patch near outer edge. Duxbury Point and reef in the distance. G. K. G.

C. Clam patch near Bolinas. A bed-rock platform, exposed at low tide. Photographed November 25, 1906.

D. Salicornia in Limantour Bay. Photographed June 5, 1907, during low tide. Shows a platform covered by an older growth, and a colony of younger plants at a lower level.

of 1907, and it was then overspread by a fresh deposit brought by Papermill Creek. The ridges varied somewhat in height, the amplitude from crest to trough ranging from 1 to 3 feet and possibly more. Their general trend was parallel to the fault-trace, but there were notable exceptions, and over small tracts the direction was even at right angles to it. In some cases, where the minor ridges were parallel, there were larger ridges traversing them obliquely. Fig. 25 reproduces a sketch map of the locality showing the greatest complexity. So far as the broad undulations of the tide lands were seen in conjunction with the ridging, the greater ridges were on the swells and not in the hollows.

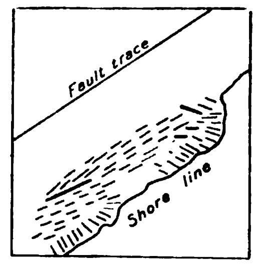
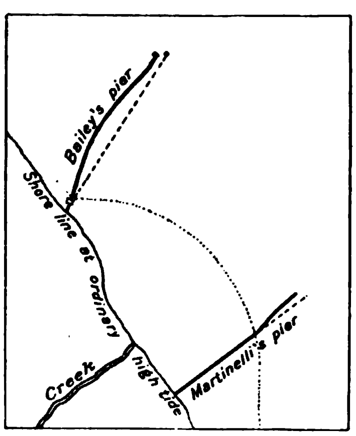


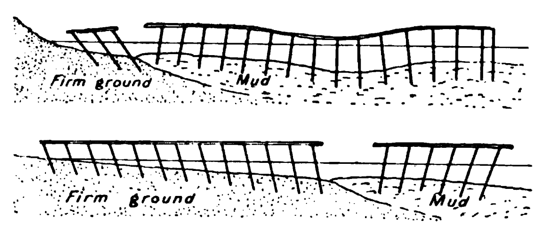
FIG. 25.—Arrangement of ridges on tidal flat near Inverness. Map.

Without going deeply into the question of interpretation, it would seem that in the production of this ridging the tidal mud must have behaved as a quasi-liquid, being thrown into waves by the agitation to which it was subjected. When the agitation ceased it became once more a quasi-solid, and preserved the form it had at the moment of change.

There was also a horizontal shifting of mud over a considerable area. Residents familiar with depths of water in the vicinity of Inverness stated that the earthquake caused a decided shoaling along the coast, but that the relation of water levels to firm ground was unchanged. It was also stated that a channel which had existed parallel to the west shore of the bay, and to which piers had been run, was obliterated by the earthquake. The shoaling might have been caused either by an uplift of the bottom or by a shifting of the mud of which it is composed toward the shore. That the second of these explanations is correct seems to be shown by the following facts.



26.



27.

FIG. 26.—Sketch of Inverness piers. Full lines show positions of piers after earthquake; broken lines show positions before earthquake. Dotted line shows shoreward limit of the shifting of bottom.

FIG. 27.—Diagrams with exaggeration of vertical scale, to illustrate deformation of Inverness piers by shifting of mud toward the shore. Bailey's pier above; Martinelli's below.

At various places along the shore, from Inverness to a point 1.5 miles southward, the tidal mud seemed to be crowded against the firmer ground at the shore, being pushed up in a ridge, as shown in the accompanying photograph. (Plate 55B.) Two piers at Inverness, light wooden structures, resting on piles and extending out several hundred feet from the shore, were telescoped. (Figs. 26 and 27.) In the case of Martinelli's pier the telescoping was shown by the inclination given to piles at the landward and bayward ends, from which it appears that the ground in which the piles were set was crowded together, so that the foundation of the pier was shortened, while the superstructure resisted shortening. The resistance was temporary only, for before the agitation ceased the pier was broken in two; and the inclination of the piles is supposed to have been given during the early stages of the tremor. Coincident with the movement of the

ground toward the shore, there was a movement parallel to the shore which had the effect of offsetting the outer end of the pier about 25 feet toward the northwest. (Plate 57A.) The resultant of the two movements, or the actual direction of shifting of the mud, was westward, or a little to the north of west; and the maximum shifting in that direction was not less than 30 feet. Rather more than half the pier, the part nearer the shore, remained straight and suffered chiefly from the slanting of its supporting piles. This part stands on the submerged delta of a small creek, and its foundation appears not to have shifted. The outer part suffered most violence near the junction of the shifting mud with the firmer ground, being there so completely wrecked that its platform fell. The photograph and map represent it after repairs had been made.

In the case of Bailey's pier, which is beyond the delta, the most important telescoping, as shown by the slanting of piles (fig. 27), was close to the shore, and nearly the whole structure was transported by the shifting mud. It also sagged more than a foot just beyond the middle, and the attitudes of the associated piles suggest that the sag corresponds to a hollow made in the surface of the mud. The pier was so badly broken as to require extensive repairs, and in making these repairs Mr. Bailey used the old material for flooring, but found that he had enough lumber remaining for 12 feet of flooring, so that he inferred a shortening of 12 feet. The whole pier was shifted to the northwest, being given a curved form (plates 57B and 58), and the maximum amount of shifting in that direction was at least 25 feet, altho the circumstances did not admit of accurate measurement. Combining the movement toward the shore with the offset parallel to the shore, it is probable that the direction and the maximum amount of shifting were about the same as in the case of the Martinelli pier.

It is a notable feature of this displacement that the disturbed material moved up the slope instead of down, so that the transfer was not only independent of gravity but opposed to it. The phenomenon, therefore, does not fall in the same category with landslides, and if properly interpreted it may throw light on the mechanics of the earthquake pulses.

The area thru which the shifting of the mud took place is indeterminate. It affected a shoal parallel to the west shore of the bay and more than a mile long. At the piers the width of the affected region was at least 400 feet and may have been much more. The reported closing of the channel suggests 700 or 800 feet as a minimum estimate, but the outer margin of the affected area was probably beneath the water of the bay and outside the range of observation. The firmer part of the Papermill delta appeared not to be included in the movement. All of the area known to be affected lies southwest of the fault-trace, which in that neighborhood is about 2,000 feet from the shore.

THE QUESTION OF LOCAL ELEVATION AND DEPRESSION OF LAND.

Introductory. — Dr. C. Hart Merriam was told by an Indian living near Marshall, on the northeast shore of Tomales Bay, that since the earthquake the clam belt on that shore had been less accessible. The tides also came higher than formerly, the highest tides surrounding his cabin, whereas formerly they did not reach it. Mr. C. J. Pease, of Olema, also stated that the clam industry on the northeast shore of Tomales Bay had been much injured by changes due to the earthquake. Thru President D. S. Jordan I was put in communication with Dr. S. S. Southworth, of Bolinas, who reported various phenomena indicating a lowering of the land on the east side of the fault, and a lifting on the west side. On September 27 and October 15, 1906, being in Bolinas and its vicinity, I made a preliminary examination of some of the features described by Dr. Southworth. They were of such a character that it seemed desirable to enlist the aid of zoölogists and botanists, and to this end a conference was soon afterward called in

A. Martinelli's pier at Inverness. Originally straight; shifted and broken by earthquake. Repaired before photograph was taken. G. K. G.

B. Bailey's pier at Inverness. Originally straight; shifted and much broken by earthquake. In subsequent repairs curvature caused by earthquake was retained. G. K. G.

A. Bailey's pier at Inverness. Another view, position of camera being approximately same as in making photograph below, taken before the earthquake. G. K. G.

B. Bailey's pier at Inverness, before earthquake. Photographed by Martha F. Schreiber. Compare A of this plate.

Berkeley, and arrangements were made for field examinations by naturalists. On October 26 Professor William E. Ritter and Mr. E. L. Michael went to Bodega Bay, where they spent several days, and at the same time Profs. Chas. A. Kofoid, H. B. Torrey, and R. S. Holway visited various points on the shores of Tomales Bay and Tomales Peninsula. On November 24 and 25 Professor Kofoid accompanied me to Bolinas for the purpose of gathering such evidence as might be afforded by marine invertebrates. On March 8–9, 1907, Professor Holway and I visited Bolinas, and on April 9–10 I was accompanied by Professor Willis L. Jepson in the same locality. On April 18 I made an examination of the Papermill Creek delta at the head of Tomales Bay, and on April 22 visited the sand-spit separating Bolinas Lagoon from the ocean. The results of these various excursions are summarized below, and reports by Professors Ritter, Kofoid, Holway, and Jepson are appended.

About Bolinas Lagoon. — In presenting the evidence as to land-movements in the vicinity of Bolinas Lagoon, first place will be given to testimony of residents, and this again will be classified according to locality, beginning with the features west of the fault-trace.

Dr. Southworth has lived in Bolinas several years, and his activities during that period have led him into almost continuous observation of the coast and the tide. There is a clam patch on the ocean front between Bolinas and Duxbury reef (see fig. 28 and plate 56B), to which he has frequently resorted at suitable stages of the tide. It has been his custom regularly to consult the tide tables to ascertain whether the water stage would expose the patch. He reports that before the earthquake there were ordinarily about four low tides in the month, occurring by daylight, during which clams might be obtained, and that since the earthquake twenty or more days are available. He infers that the land was lifted at least a foot, possibly more, at the time of the earthquake. He states also that about 5 miles to the northwest there is a tract, exposed only at low tide, where abalones are abundant, and that people living near there have found them much more accessible since the earthquake than before. In Bolinas Lagoon a channel between Pepper Island and the mainland is not now navigable at certain tide stages which formerly made it entirely navigable.

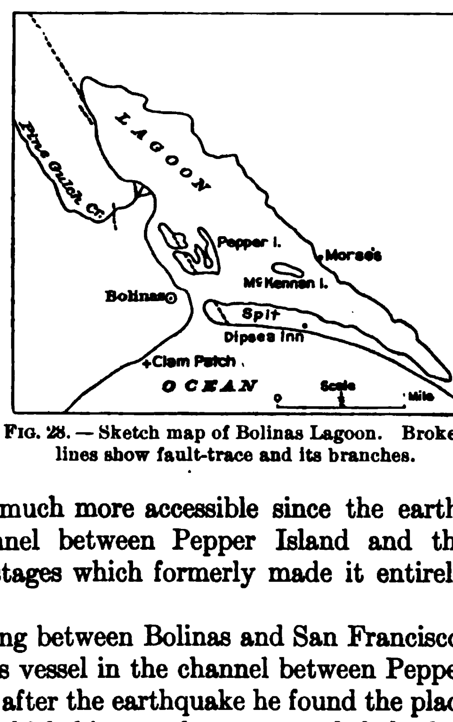


FIG. 28. — Sketch map of Bolinas Lagoon. Broken lines show fault-trace and its branches.

Dr. Gleason, owner and master of a vessel plying between Bolinas and San Francisco, states that formerly it was his custom to turn his vessel in the channel between Pepper Island and the west end of the sand-spit, but that after the earthquake he found the place too shoal, so that, after a number of trials in which his vessel was grounded, he has adopted the practice of entering the lagoon stern first, to avoid the turn.

The following observations pertain to localities east of the fault. A road which skirts the northeast shore of the lagoon is not altogether on the mainland, but in places follows the strand between high and low water, and if it is used at high water the horses must ford. Dr. Southworth states that since the earthquake these fords have become more difficult, so that to pass them safely or comfortably they must be reached when the tide, as indicated by the tables, is lower than was formerly necessary. Mr. B. C. Morse, however, who lives on the mainland east of McKennan Island, and who ordinarily crosses the lagoon to Bolinas every day, states that he has noticed no change in the relation of

water to land along his water-front. Dr. Southworth has found the navigation improved at various places in the eastern part of the lagoon, the water being deeper than formerly for the same normal state of the tide, and this observation is confirmed by Mr. Morse, who now at high tide sails over a portion of McKennan Island which could not formerly be crost with a boat. Various residents are of opinion that the sand-spit, except at its extreme western end, is lower than formerly. A lady who has lived at Dipsea Inn several years states that before the earthquake the spit was overtopt by waves only during storms with heavy winds, but that since the earthquake waves frequently wash over it.

It will be observed that all this testimony, with the single exception of Mr. Morse's observation of water-levels near his house, tends to show a general sinking of the land east of the fault, and a general rising of that to west of it.

Professor Kofoid, in seeking evidence from the distribution of marine life, found the barnacle the most available form. It is abundant at many places; its shell remains as a witness after the death of the animal, and its upward limit bears, at many places, a definite relation to the line of high tide. The best places found for observation were certain groups of piles at Bolinas and along the northeast shore of the lagoon. From a study of these localities it appeared that in the upper part of the barnacle zone the percentage of dead shells is notably greater on the west side of the fault than on the east side, but there is not a well-marked zone of dead barnacles on the west side, nor is there a zone of exclusive young barnacles on the east side. The evidence thus gives a qualified support to the theory of elevation and subsidence. Outside the lagoon, on the open sea-front, the upper limit of barnacles is too indefinite and irregular to be available for a study of this character.

Visiting Pepper Island in company with Professor Holway, I found the position of the fault-trace clearly indicated by a difference in the color of the vegetation. The island is low, only a narrow strip at the south remaining above water at ordinary high tide, and from this strip there is a gentle slope toward the north and northwest. The vegetation on the highest part is somewhat varied, but the lower slopes are occupied almost wholly by a single species of *Salicornia* (pickle-weed). This is locally the lowest lying of the shore forms, and it descends the slope to a somewhat definite line beyond which the mud is bare. It is evident, therefore, that its lower limit is determined purely by physical conditions and not at all by the competition of other plants. It is thus peculiarly sensitive to changes in the relation of land to water. West of the fault a broad area covered by this plant presented, at the time of the visit, a brownish-green color, while the adjacent areas east of the fault had a dull brown color. The contrast was so strong that the eye could readily trace the line of the fault. We found also that the ground east of the fault was, in general, lower than the ground at the west, and I afterward made a series of measurements showing the average difference in elevation to be 12 inches.

Pepper Island was subsequently examined by Professor Jepson, who not only traced the brown color of the *Salicornia* to an abundance of dead and dying plants, but found considerable corroborative evidence in the condition of other species living at slightly higher levels. On McKennan Island a similar condition was found. The island is girt by a zone of *Salicornia*, the outer or lower belt of which was found to be brown. A single measurement of the vertical range of dead and dying plants gave 10 inches.

The northeastern shore of the lagoon was examined for evidence of similar character, but the result was less satisfactory. The lowest plant growth is not everywhere the same and the local conditions are materially different. The slope is less gradual, the soil is more gravelly, and there is deposition of detritus eroded from the land by streams and waves. At some points a belt of plants at the extreme limit appeared to be suffer-

ing from some adverse condition, but elsewhere the normal green color was continued to the lowest limit. At the head of the lagoon and just to the east of the fault-trace is a considerable tract of *Salicornia*, of which the low-lying parts showed a brown color, but the distribution of vigorous and sickly plants was less simple than on the island and its causes were not fully understood. I afterwards visited the north slope of the spit to see if the condition of its vegetation corresponded to that on the islands, but found the evidence complicated by another factor. The overflow of the spit by waves during the past winter had washt a considerable amount of sand down the north slope, and this sand suffocated large tracts of *Salicornia* and other plants.

In the discussion of these data, the first point to be noted is that the killing of *Salicornia* thru the lower part of its zone definitely indicates a lowering of the ground on which it stands. The plant normally travels down the slope as far as it can tolerate the tidal submergence and there stops; and its inability to sustain itself in a well-defined belt constituting the lower part of its former range shows that the submergence in the belt has become intolerable. The amount of submergence is shown by observation on McKennan Island to be at least 10 inches, and if allowance is made for a certain amount of lag in the response of the plant to change of condition, the lowering of the land may have been several inches more than this. If McKennan Island and the eastern part of Pepper Island subsided the same amount, it is probable that the only change on Pepper Island was a subsidence of its eastern part, the western part remaining at its former level. In that case the amount appears sufficient to account for the overwashing of the spit, altho no measurement is there practicable.

The tract of land, whose subsidence appears to be demonstrated by the botanic evidence and the overtopping of the spit by waves, is bounded on the southwest by the fault, but its other limits are not known. In the immediate vicinity of the fault it may reach the head of the lagoon; that it does not extend beyond is rendered probable by the fact that there is no vertical dislocation in the fault-trace at a point about one mile northwest of the lagoon where the trace is favorably exposed on flat ground. It may be possible that the area of subsidence is limited on the northeast along an old line of dislocation which coincides approximately with the northeast side of the lagoon. This dislocation has not been determined by a study of the geologic structure, but is indicated by the physiography, and was presumably concerned in the making of the basin occupied by the lagoon.

The evidence of elevation west of the fault is less coherent. Dr. Southworth's observations on the clam patch give a presumption in favor of elevation, but they are not well supported by the evidence from barnacles and plants. The botanic evidence indicates that the entire dislocation shown by the measurement on Pepper Island is a subsidence on the east and does not include elevation on the west. The evidence from the barnacles suggests, without proving, a slight elevation at the Bolinas wharfs, but by no means indicates so great an elevation as would be necessary to account for the increased facility in reaching the clam patch. Dr. Gleason's report of the shoaling of water in a channel near Pepper Island undoubtedly shows a local change, but such a change may have been produced by a horizontal shifting of unconsolidated material such as occurred in Tomales Bay. On the other hand, it is not possible to explain the phenomena of the clam patch by a hypothesis of shifting bottom, for the sand in which the clams live is contained in shallow basins of visible bedrock, and any change in the relation of surface to tide at that point is a bedrock change. As the Rift belt with its numerous earlier dislocations extends nearly to the clam patch, it is not impossible that there were differential movements west of the fault-line and that the ground occupied by the clam patch and the abalone patch rose independently of the western division of Pepper Island.

About Tomales Bay. — Professors Kofoid, Torrey, and Holway examined practically the whole shore of Tomales Bay, and also visited the outer or ocean side of Tomales Point. Their attention was directed especially to the condition of barnacles at the upper limit of the zone of marine life, and the evidence they found does not show any change in level, either by elevation or subsidence. It is their opinion that the injury to the clam industry along the northeastern shore of the bay is referable to other causes, including at some points the exceptional inwash of detrital material from the shore, and at others the shifting of loose material toward the center of the bay.

After the discovery of the vertical dislocation in Pepper Island, I visited the Papermill delta at the head of Tomales Bay in search of similar evidence of displacement, but failed to discover it. There are on the delta several tracts on which water stands after the fall of the tide, and the plant growth, especially *Salicornia*, shows deterioration in these areas; but the areas are not systematically related to the fault-trace. They occur on both sides and at least one of them is intersected by the trace. They constitute part of the evidence of a gentle, broad undulation of the delta surface, which appears to have been occasioned by the earthquake. A tentative theory to account for this undulation is that lenticular bodies of soft clay, included in the delta deposit, experienced a certain amount of flow during the earthquake period. The lane of water following the fault-trace, and described on an earlier page, is an independent phenomenon closely associated with the fault, and the depression causing it does not extend indefinitely toward the east. In a general way, the half of the delta east of the fault stands as high as the half at the west. On the lower slope of the delta, beyond the region of plant growth, there is a tract east of the fault which received the principal deposit of sediment brought by the floods of 1907. The localization of this deposit suggests that the transporting current may have been guided by a depression of the surface, but if so the depression was not bounded on the one side by the fault line; its southwestern boundary is a distributary of the creek. As the tract on which this deposit took place is opposite a portion of the tract in which mud was shifted toward the southwest shore, it seems possible that the area of shifting here included practically the whole width of the bay, and that the resulting elevation of the bottom toward the west was accompanied by a lowering of the bottom toward the east. In that case, the apparent lowering of the clam zone at various points on the northeast shore may be correlated with the phenomena near the head of the bay, and the whole ascribed to a general shifting of loose material in the bottom of the bay toward the west.

Bodega Bay. — As the title of Bodega Bay is variously applied on different maps, it is proper to specify that the body of water here intended is the land-lockt lagoon east of Bodega Head, and not the open roadstead farther south. Professor Ritter examined this with care, studying especially the distribution of barnacles, and found no evidence of absolute or differential change of level.

Summary. — At Bolinas Lagoon, subsidence occurred east of the fault, its vertical amount being approximately a foot. The subsided tract included the greater part of the area of the lagoon, and may have had its eastern limit along the eastern shore of the lagoon. The subsidence was possibly a continuation of the local movement of dislocation by which the basin containing the lagoon was created. There may have been local elevation of a tract extending from Bolinas westward and northwestward. The evidence is not demonstrative, but leaves a presumption in favor of such elevation.

About Tomales Bay and Bodega Head there was probably no appreciable change in the general elevation of the land, most facts which tend to show such change being explained by assuming that in Tomales Bay there was a general shifting of mud and other incoherent material toward the west. Such shifting had been fully demonstrated in the vicinity of Inverness.

Postscript. — Since the preceding paragraphs were written, some additional data have been gathered bearing on the question of the elevation of land between Bolinas and Point Reyes. As the most satisfactory biological evidence with reference to changes in level had been found in the response of the plant *Salicornia*, it occurred to me that pertinent information might be obtained by examining the lower limit of land vegetation at Limantour Bay. That bay is an extensive, ramifying, drowned valley lying east of Point Reyes promontory. It is separated from the ocean by a spit, past the western end of which a channel is maintained by tidal currents, just as in the case of Bolinas Lagoon. The eastern end of the bay is at the western base of the ridge bounding the Bolinas-Tomales trough, and is 8 or 10 miles northwest of the abalone locality.

If the land in this locality was raised at the time of the earthquake, the height of the tide at all stages, with reference to the land, would be lower; and the lower limit of *Salicornia*, being dependent on the relation of the land to tide water, would descend the slope in response to the change in level. The feature, therefore, to be lookt for was a new growth of *Salicornia* at a lower level than the older growth. Such new growth was actually found (June 5, 1907), not in a continuous belt, but in numerous patches having certain common characteristics.

At the points visited the tide marsh characteristically ends in a little step or bluff about 8 inches high. Above this step the gentle slope is covered by a mat of vegetation in healthy condition, the dominant plant near the step being *Salicornia*. Below the step is a mud surface, which usually inclines more rapidly than the platform above. If I understand the origin of this topography, the step has arisen from the gradual bayward extension of the platform, which, by reason of its vegetal covering, is enabled to arrest mud suspended in the water. There is also doubtless an accumulation of the roots and stems of the *Salicornia*. In places there are outlying platforms of the nature of islands and similarly covered by *Salicornia*. On the other hand, the broader platforms are interrupted by channels thru which the tidal waters escape, and there are also lake-like hollows abruptly margined by steps a few inches high. The slope below the step is ordinarily of bare mud, but on it are numerous patches of young *Salicornia*, and there are similar tracts in tidal channels and in some of the lake-like hollows inside the platform. The vertical range of this young growth is quite definite, its lower limit being from 13 to 16 inches below the outer edge of the platform. In some cases the young growth is straggling, but usually it makes a mat as close and complete as on the platform above, and the height is nearly as great. It is distinguished from the older growth chiefly by a slight difference in color. Whether such a luxuriant and dense growth of *Salicornia* could be produced in the period of 13.5 months, I am not prepared to say. Except for that doubt, however, the phenomena are just such as would be expected to follow an elevation of the land.

In an estuary at the edge of the bay were two fence stakes on which barnacles were set. At the upper limit of the barnacles, I examined a dozen individuals, finding them all alive, and I saw none of the adherent plates which remain after the death of the old barnacles. I did not learn the history of these stakes. If placed after the earthquake, the evidence of the barnacles would not be in point. If placed before the earthquake, the evidence of the barnacles, so far as it goes, is opposed to that of the new colonies of *Salicornia*.

Second Postscript, added to proof sheets in November, 1907. — Early in October, 1907, Dr. S. S. Southworth reported that the clam patch near Bolinas had again become less accessible, its relation to tides being practically as before the earthquake. The apparent change was not associated with any precise date, but it had been suspected since the middle of summer. On October 17 I visited the locality, selecting a time when the predicted sea-level at low tide was approximately the same as on November 25, 1906, when I had taken the photographs reproduced in plate 56B and plate 56C.

For November 25, 1906, the predicted height of low-water at the San Francisco entrance was 2.1 feet; for October 17, 1907, 2.2 feet. The comparison of the clam patch with the view made eleven months earlier showed a marked difference, a much larger area being submerged at the later date. Four days afterward, when the predicted height of low-water was 0.3 foot, I again compared the appearance of the clam patch with the photograph, finding the water-stage somewhat lower than when the photograph was made. As the tide rose its stage was found to coincide with that shown by the photograph one hour after low-water, and the calculated allowance for the corresponding change in water-level at the San Francisco entrance is about 0.3 foot, so that the predicted tide-stage for that moment was 0.6 foot. As the predicted stage at the time represented by the photograph was 2.1 feet, there was an apparent discrepancy of 1.5 feet. If this was occasioned by a change in the height of the ground at the clam patch, then there was a subsidence of 1.5 feet between November 25, 1906, and October 21, 1907. Before accepting so important a conclusion it should be checkt in every practicable way, and especially by comparing the water-stages at the clam patch with simultaneous water-stages as recorded at the tide-gage station of the U. S. Coast Survey in the entrance to San Francisco Bay. The distance of that station from the clam patch is about 15 miles, of which one mile is inside the narrowest constriction of the Golden Gate. On the days of observation at the clam patch the sea was calm, except for a moderate groundswell, so that the normal equilibrium of the water-surface between that point and the tide-gage was presumably not impaired by meteorologic influences. Off the clam patch the groundswell broke at a distance from the shore, leaving the water so quiet at its actual margin that its level could be observed with little error. The general and local conditions were thus favorable for a comparison of water-stages at the two points; and the numerous details of the photograph of November 25, 1906, made it possible to identify, with close approximation, the arrival of the tide at the same plane on October 21, 1907. The observations at the tidal station, for which I am indebted to Capt. Aug. F. Rodgers, Assistant U. S. Coast Survey, were made with the tide-staff at low-water, and are referred to the arbitrary zero of the tidal station.

	Feet
At low-water on the afternoon of Nov. 25, 1906, the tide-staff reading was	6.10
At low-water on the afternoon of Oct. 21, 1907, the tide-staff reading was	5.61
In the hour following low-water the computed rise of the tide was 0.3 ft.; and this gives as the height of water at the time of the observation at the clam patch . . .	5.91
Difference	.19

Thus the discrepancy of 1.5 feet, deduced from a consideration of the predicted tides, is reduced by a comparison of the observed tides to about 0.2 foot, a quantity so small as to be referable to errors of observation.

Before tide-gage records were obtained I had revisited Pepper Island and Limantour Bay. On Pepper Island the vertical dislocation was remeasured and found to be unchanged. At Limantour Bay the subject of examination was the condition of the new growth of *Salicornia*. If the land had subsided since the preceding June, the colonies of *Salicornia* which had invaded the mud flat (plate 56D) would have been subjected to unfavorable conditions, and might be expected to show the influence of those conditions. All the colonies that had previously been observed were reëxamined and they were found, without exception, to have deteriorated. The green heads, which had formerly testified to their lusty growth, had become much less numerous and were modified in color; their stems were blackened on the surface and had become somewhat curled, and in general they appeared less healthy than the plants of the same species growing at higher levels. Where the slope was continuous, there was a fairly sharp line of separation between the healthy and unhealthy plants, and two measurements indicated the zone of impairment to have a vertical range of 10 inches.

The comparative observations of water-stages show that the land at the locality of the clam patch has not recently undergone the suspected depression, as compared to land at the tidal station near San Francisco. If an important change has taken place at one locality, it has affected the other also. On the other hand, it is noteworthy that Dr. Southworth's observations at the clam patch (first of its increased accessibility, and after of its decreased accessibility) led to two predictions as to the condition of *Salicornia* in Limantour Bay, both of which were verified. Their success in prediction gives assurance that they record an actual change of some sort — a change not restricted to the locality of the clam patch. The two lines of evidence taken together — the leveling by water-plane from the tide-gage to Bolinas, and the observation of shore conditions at Bolinas and Limantour Bay — suggest the possibility of a general change in the relation of land to sea, affecting the whole coast from San Francisco to Limantour Bay. So far as the observations go, such a change might pertain to either land or sea. In the line of this suggestion it is to be noted that November 25, 1906, falls within a period of exceptionally low tides at San Francisco entrance. For 21 low tides, from November 20 to November 30, the mean of the observed heights was 1.08 feet below the mean of the predicted heights. From October 17 to October 21, 1907, on the other hand, the mean of 10 observed tides was only 0.32 foot below the corresponding mean of predicted tides. The subject appears to deserve further investigation and discussion than is practicable while these pages are in press.

The observations which occasioned this postscript, while suggesting lines of enquiry which may profitably be followed, do not materially affect the conclusion already summarized as to local changes in the elevation of the land. A tract, including the east part of Pepper Island and much of the area of Bolinas Lagoon, subsided at the time of the earthquake, the amount of subsidence at the point of most satisfactory measurement being 12 inches. The region west of the fault, including the ocean coast from a point near Bolinas to Limantour Bay, may or may not have been uplifted at the same time, and may or may not have subsequently subsided. The evidence is incomplete and apparently somewhat conflicting.

Special reports on the biologic evidence follow.

REPORT ON A BIOLOGICAL RECONNAISSANCE OF BODEGA BAY REGION.

By William E. Ritter.

Accompanied by Mr. E. L. Michael, I examined the Bodega Bay region on October 26–30, for evidences of a faunal modification resulting from the earthquake of April 18, 1906.

My first effort was to secure information from residents of the district bearing on the question. A number of families living on the shores of Bodega Bay have their dwellings close to the water's edge. Since the bay is small, closely land-lockt, and hence especially free from surf, and since these families spend much time on the water with their small boats, which they beach on the gradually shelving shores or tie to their little private piers, it seemed that their testimony would be peculiarly reliable. It appeared that any appreciable change of level of the water along the shore or any noticeable effects on the shore life would hardly escape detection. I talked with five persons of this sort, each by himself. All were unequivocal in affirming that neither the level of the water nor the animal life of the bay were in any wise altered by the earthquake.

The earthquake fault at the only point at which it has been located here, passes thru the sand-dunes at the head of the bay; and from its general course and the place where next observed to the south, must have past nearly parallel with the eastern shore of the bay and either have followed the shore or have been to the landward of the shore. In other words, nearly if not the whole of the bay, together with the peninsula of which Bodega Head is a part, is on the west or seaward side of the fault. All the facts we were able to gather by direct observation pertain to the rocky shore of the bay side of the peninsula. Since the rock here is a firm granite, and since in some localities the walls are nearly perpendicular, are even-faced, and are washt by the waters thruout the day excepting at extreme low tide, they are very favorable for furnishing testimony of the kind sought. The question to be answered was: Do the organisms that live immovably fixt to the rocks show evidence of having either extended or withdrawn the upper limit of their vertical distribution within recent time? The organisms that would be available as testimony would be those that are most permanent in structure, and extend up to the very limit of the high tide. Of first importance are the barnacles, two species, *Balanus balanoides* and *Chthamalus stellatus.* A species of *Mytilus*, and perhaps one or two species of marine algæ, are also more or less available. Our attention was given to the barnacles chiefly, but somewhat to the mussels also. Neither of us was sufficiently familiar with the algæ to make much use of them.

We could get no evidence that any of these organisms had either extended or withdrawn their limits of distribution. In the absence of accurate knowledge on the rate with which barnacles develop, there might be some uncertainty as to whether the limits had been extended; since, however, the individuals at the upper limit were not found to be in general smaller than those farther down; and further, and still more importantly, since the remains of dead individuals were quite as numerous proportionally in the upper zone of distribution as in the lower, we could but conclude that there was an absence of evidence of extension. In other words, there was no evidence of subsidence of the shore.

As to the question of whether the shore has been elevated at this point, the evidence I think is more positive. Not only is there lack of proof that elevation has occurred, but there is ample proof that it has not. This is furnished by the barnacles chiefly. On the vertical granite walls above mentioned, these organisms almost completely cover the surface up to about 7 feet above mean low water. As already stated, the remains of dead individuals are uniformly distributed thruout the area; or, to speak more accurately, they are not more numerous proportionally in the upper limit of distribution than in any other portion, as would surely be the case had the upper limit been lifted above the former high-water mark. It should have been pointed out that the 7 feet to which the barnacles extend must be very near, if not quite the limit, of high tide.

The character of the remains of dead animals is such as to preclude, I believe, being misled by the facts. In addition to the heavy calcareous wall which characterizes the superstructure of the animal, there is a well-defined continuous platform closely fused to the substratum to which the animal adheres. After death the superstructure of the shell falls away, leaving the platform as a smooth, hard, calcareous scab clinging to the rock. This is very durable, as one can see by observing old piles that have been taken from the water and to which these barnacle remains cling. Had any appreciable elevation of this shore occurred, there would surely be a zone of dead barnacle shells at the upper range of the distribution. The testimony of the mussels, so far as it goes, is confirmatory of that furnished by the barnacles.

REPORT ON A BIOLOGICAL RECONNAISSANCE OF TOMALES BAY REGION.

BY CHARLES A. KOFOID.

On October 26–28, 1906, in company with Profs. H. B. Torrey and R. S. Holway, I made an examination of the shore of Tomales Bay to obtain evidence of faunal modification resulting from the earthquake of April 18, 1906. The places specially examined were as follows: the northeast shore from Millerton to Preston Point; Hog Island near the mouth of the bay; the southwest shore from near Tomales Point to the region opposite Marshall, and from Inverness to the head of the bay. The outer face of Tomales Point was also explored for a short distance near "Shell Beach."

Search was made for evidence of a change in level in the two sides of the bay and especially for evidence of depression of the northeast shore and elevation of the southwest shore. For this purpose critical examination was made of barnacles *in situ* on rock in place along the shores between tide levels. The fauna of the bay includes no generally distributed organisms attached to rock within tide levels except the barnacles (*Balanus* sp.). Mussels are rare and there are very few attached seaweeds far from the mouth of the bay.

The barnacles are, however, sufficiently abundant and widely distributed to afford an excellent index to any recent change in levels. If the northwest shore line, about 0.5 to 1.5 miles from the main earthquake trace, had been deprest even a few inches we might expect to find young barnacles, the young of the year which are easily distinguished by their brownish-gray color, softer texture of the shell, and certain structural features, invading the new territory above the old to an extent equivalent to the depression. If the southwest shore had been elevated, we should expect to find a number of dead barnacles in the region above the old barnacle limit and a relative absence of young in the upper levels. The upper limit of the growth of barnacles lies below the level of highest tides, and is more or less distinctly marked, according to the exposure to prevalent currents and wind and to exposure to the sun; and it is also modified by the slope and texture of the substratum.

The two shores present strong contrasts in the matter of exposure to prevalent winds, to the sunshine and in the texture of the substratum, the rocks of the northeast shore belonging to the Franciscan, more or less metamorphosed, and those of the southwest shore being of a granitic nature. These contrasts produce considerable modifications in the distribution of the barnacles.

A critical examination of the data reveals *no conclusive evidence of any recent change in the distribution of barnacles that can be attributed to a change in the levels of rocks in place.* There is no sharp and uniform contrast between the two sides of the bay in the matter of the distribution of these organisms. There is no uniform or extensive invasion of higher levels by young barnacles on the northeastern shore and no marked destruction of old barnacles and absence of the young at high levels on the southwestern shore. The conclusion is reasonably certain that there has been no appreciable change in levels of either shore as a whole.

Especial care was taken with the examination of the rocky shores of Preston Point which is crost by the main fault, but even here there is no biological evidence of a change in levels on the two sides. In many regions barnacles have been killed in great numbers, apparently by silt in the waters. In other cases barnacle-coated substrata have been shifted with the mud, sand or gravel in or on which they lie, but such changes are of a local or superficial character. Hog Island, which lies very near the line of the fault but is not crost by it, shows no uniform change in its barnacle fauna. The outer sea-cliff of Tomales Point, tho very much shattered and with considerable talus from rock falls resulting from the earthquake, shows no disturbances in its fauna traceable to seismic movement. Local testimony of dealers in fish, of fishermen and of clam diggers indicates a great falling off in shipment of clams since the earthquake, traceable to departure of clam diggers, destruction of clams in places, by shifting of clam beds or their burial with detritus from cliffs. No change of levels which might not be traceable to shifting of loose deposits was noted.

There was local testimony of increased wash along the railroad embankment skirting the northeastern shore, or sinking or rising of known shoals in the bay, and of a depression of the gravel spit on which the fishing village stands. Probably all of these phenomena are explicable as the results of local loosening up of the railroad embankment and shifting of loose deposits, rather than as a result of a general movement of the earth's crust.

REPORT ON A BIOLOGICAL EXAMINATION OF THE BOLINAS LAGOON REGION, NOVEMBER 24–25, 1906.

BY CHARLES A. KOFOID.

Bolinas Lagoon. — The distribution of barnacles along the shore, on the piles, etc., was examined with reference to possible changes in level, near Bolinas wharf on the western side of the lagoon and on Morse's wharf on the eastern side, the principal locations on which barnacles occur about the bay. In neither case was there evidence or local testimony of disturbance in levels of the ground on which the barnacle-bearing substrata were located. The possibility of local slumping of soil is not, however, entirely excluded. No barnacles on rock in place were observed in the bay.

There is no evidence from the distribution of barnacles of any change in level of the eastern side of the bay. There is neither any marked destruction of old or absence of young in the upper levels such as would follow elevation, nor any marked recent occupation of an upper belt by young barnacles such as would follow depression. On the western side of the bay, on the piles of the warehouses at the landing, there was a faintly defined zone 6 to 8 inches wide in which the proportion of dead barnacles was unusually large. The percentage of dead in the uppermost levels on Morse's pier on the eastern side of the bay varied from 2 to 35 per cent with predominant range of 10 to 20 per cent. On the piles on the western side at similar levels, the proportion of dead was predominantly 40 to 60 per cent and not infrequently ran above these figures. Below this upper belt there was frequently less destruction and a relatively greater number of young than was found in the uppermost levels. It may be that this destruction was due to elevation, tho the uppermost belt of barnacles is still just submerged at a 5.4-foot tide. It might also be due to the considerable increase of silt attendant upon the large amount of talus shaken into the bay and along the adjacent shore line by the earthquake. The fact that barnacles attached themselves to and throve on buildings thrown into the bay not far from the piles in question, would indicate that destruction by silt was confined to the time of the earthquake or that destruction did not take place as a result of silt.

The "studio building" at Bolinas, which was thrown into the bay by the earthquake and raised some months later, was well covered on submerged portions by barnacles, mainly half or two-thirds grown. This fact makes it certain that the young barnacles have been attached in large numbers since the earthquake, and that their distribution, therefore, affords critical evidence of change in levels.

The Sea Coast Line. — The evidence here from the distribution of barnacles is inconclusive, owing to the great range of movement of water in the breakers and the relative scarcity and small size of the barnacles present. There was no evidence of any change of levels, but their numbers are probably too small to afford evidence of a movement of a few feet only.

The Clam Patch. — The evidence of elevation here is entirely in the nature of testimony. The barnacles on rock in place in this region are too near the low-tide level to afford a satisfactory criterion. A few rocks in place near the upper levels show no trace of extensive destruction of barnacles such as might follow an elevation of 1.2 feet which Dr. Southworth believes to have taken place. But here again the biological evidence is too incomplete to have much weight. There is no doubt that there were clams in a shallow gravel bed resting on rock in place and abundantly exposed at a 2.1-foot tide.

In my opinion, from the evidence in hand, there was no depression of the eastern margin of Bolinas Lagoon as the result of the earthquake of April 18, 1906. Dr. Southworth's testimony, taken in conjunction with the destruction of barnacles in the upper levels on the western side of the bay, suggests the possibility of a small elevation on that side.

EXTRACT FROM REPORT ON A RECONNAISSANCE OF TOMALES BAY REGION.

By R. S. Holway.

Below is a copy of the few notes made by me during the trip to Tomales Bay, October 26–28, 1906. The object of the trip was to examine the shore lines of the bay for indications of recent changes in level as shown by the effects on animal life. Drs. Kofoid and Torrey, the biologists of the party, recorded observations in detail and I have merely the general note as follows:

"The upper limit of barnacles was found to be a quite sharply defined line on the rocky shores of the bay. Any recent change in level of a foot or more would have been easily detected in my judgment. No evidence of such change was found. . . ."

REPORT ON AN EXAMINATION OF PLANTS ON PEPPER ISLAND, BOLINAS LAGOON, APRIL 9, 1907.

By Willis L. Jepson.

Salicornia ambigua Michx. Pickle-weed. — This is the most abundant species and forms extensive colonies on both sides of the fault-trace. The difference in color of the areas on the two sides of the trace at once strikes the eye, the east area being dull or dead brown, the area west a livelier or greenish brown. This difference in color was found to be correlated with a difference in health. The plants west of the fault are in normal condition; the plants east of it are either dead or dying. Dead plants still standing show wasted or shrunken black stems. Dying plants show shrunken main axes bearing above a few short joints of green which are very much thicker than the main axis. In the normal plant the joints are no thicker or scarcely thicker than the main axis. A broad and very marked zone of dead or dying Salicornia surrounds McKennan Island which lies east of the fault.

Statice Limonium L. var. *californica* Gray. Sea Lavender. — Rather common in small areas on both sides of fault-trace. West of the fault plants are in normal condition, with large bright green leaves. East of the fault plants are dead or unhappy. Dead plants consist of nothing but caudices or short branching stems which form miniature forests of black stumps in the lowest places. Unhappy plants are those struggling to maintain existence and showing only a small tuft of small leaves. Similar colonies of dead plants were found on McKennan Island.

Grindelia cuneifolia Nutt. Marsh Grindelia. — The majority of the plants east of the fault are dead. Many plants west of the fault are dead, especially immediately west of the fault. The dying out is, in the main, doubtless due to old age in the colony.

Mesembryanthemum æquilaterale Haworth. Sea Fig. — Plants immediately west of the fault were healthy. One plant was found immediately east of the fault; this was killed completely.

Distichlis spicata (L.). Salt-grass. — Plants west of fault were thriving more than plants east in adjacent areas. (This species ranges to 600 feet above the sea.)

Frankenia grandifolia C. and S. Yerba Reuma. — Similar slight differences as in the preceding case.

Triglochin maritima L. Arrow-grass. — Coming up freely like young blades of grass west of the fault. Not appearing at all or reluctantly on east side.

Jaumea carnosa Gray. Fleshy Jaumea. — Less readily found on the east side of the fault. Plants on the west side were in somewhat better condition.

Populus species. Planted. — All individuals on east side of fault were dead.

Summary. — The difference in the health of the plants east and west of fault-trace indicates comparatively recent changes in conditions and would be explained by the assumption that there had been a change of level east of the fault. If there has been no such change it would be difficult to say why the affected areas should conform closely to the fault-trace. The plants on McKennan Island were also examined. The argument in favor of assuming a depression for Pepper Island east of the fault would hold good for McKennan Island. On the other hand, I should be strongly against the opinion that the condition of shore-line plants indicated a change in level on the east shore of Bolinas Lagoon.

MUSSEL ROCK TO CRYSTAL SPRINGS LAKE.

Course of the fault-trace. — The point at which the fault-trace intersects the shore, on emerging from the ocean on the south side of the Golden Gate, is only approximately known. About 0.875 mile to the southeast of Mussel Rock, it has been located with precision at its intersection with the wagon road on the west side of the coastal ridge a little below its crest, and thence followed continuously for many miles. Projecting its course, there determined, in a northwesterly direction, it would pass out to sea in the midst of the large landslide which scars the coast immediately to the north of Mussel Rock, where the basal beds of the Merced series rest upon the older rocks. At the time of the earthquake there was an extensive movement of the landslide, and a tongue of landslide material, about 50 feet high and about 200 feet wide, was projected into the ocean across the narrow strip of beach.[1] This movement naturally obscured all evidence of the position of the fault-trace, which was doubtless overridden by the slide. All about the crest to the east of the landslide, and on its south side, the ground was greatly disturbed by fresh landslide cracks, scarps, and fissures, extending well back from the edge of its encircling cliffs. It appears to be probable that not only did the movement of the landslide obscure the evidence of the fault-trace, but also that the latter was here diffuse and scattered, and that the displacement was superficially taken up by the plasticity of the landslide material.

From the point southeast of the Mussel Rock slide where the fault-trace resumes its definite and easily recognizable character, to Crystal Springs Lake, our information regarding the course of the fault-trace and the earth movement on the fault is in part from observations made by Mr. Robert Anderson, and in part from observations recorded in a paper by Herman Schussler,[2] supplemented by the observations of Mr. H. O. Wood, Andrew C. Lawson, and others.

South of the road, at a point 0.875 mile southeast of Mussel Rock, begins the furrow which marks the surface path of the fault. The furrow as such does not cross the road to the north of this point. The side-hill slope, however, is very much fissured by landslide movements both above and below the road, and scarps are seen. From this point, the furrow runs uninterruptedly southeastward to the east side of the north end of San Andreas Lake, where, with a course of about S. 33° E., it passes beneath the waters of that reservoir. As it approaches the lake, the trace of the fault does not lie in the axis of the valley, but runs along its eastern side. It thence passes thru the lake on the northeast side, crossing a number of small promontories, to the east end of San Andreas dam; thence, with a course of S. 37° E., it traverses the east side of the valley between this dam and Lower Crystal Springs Lake, passes thru the latter and intersects the old dam between Upper and Lower Crystal Springs Lakes. Beyond this it skirts the southwest side of the upper lake, partly in the water and partly on the projecting points, and finally leaves the lake about a 0.25 mile from its end, for the stage of the water of April, 1906, having here a course of S. 40° E.

The mean course of the fault, as thus closely followed from the vicinity of Mussel Rock to the end of Upper Crystal Springs Lake, a distance of about 15 miles, is S. 36° 30′ E. But the trace is not a perfectly straight line. Between Mussel Rock and San Andreas

[1] On February 27, 1907, according to the observations of Mr. H. O. Wood, this projecting tongue of landslide had been entirely removed by the action of the waves, and alinement of the beach and sea-cliff had been reëstablished.

[2] The Water Supply of San Francisco before, during, and after the Earthquake of April 18, 1906, and the Subsequent Conflagration. New York, 1906.

dam, the trace of the fault is slightly concave to the straight line connecting these two points on the fault, the concavity being to the southwest. Between San Andreas dam and the end of Upper Crystal Springs Lake, the trace of the fault is again slightly concave to the straight line between these points, but is on the opposite side of the fault, the concavity here facing the northeast.

Characteristics of the fault-trace. — For this stretch of from 14 to 15 miles, Mr. Robert Anderson, who examined this territory under direction of Prof. J. C. Branner, describes the trace of the fault as marked by a belt of upturned earth resembling a gigantic mole-track. The rupture may be traced along every foot of the way when not below the waters of the lakes. It varies in width from 2 or 3 feet to 10 feet, but at times branches out into several furrows that include a space of 100 feet or more in width. Such branches sometimes join again after a short interval. Sometimes it forms a crack 2 or 3 feet wide and several feet deep, and in other places shows a vertical wall of soil on one side or the other, several feet high. The typical occurrence in turf-covered fields is a long, straight, raised line of blocks of sod broken loose and partly overturned. It is thus shown in plate 61A, B.

Associated with the fault fractures are many lateral cracks, extending away from the fault in a northward, or north slightly eastward, direction; that is, at an oblique angle to the northeast side. These cracks were especially abundant along the northeast side of the northern half of Crystal Springs Lake, and between there and San Andreas Lake. In places they run off every foot or few feet for a distance of 100 yards or more, and again they do not form for some distance. They vary in size from minute crevices in the earth to fractures a foot or more in width. Here and there they form lines of broken sod very like the main furrow in size, while they have a length of from a few feet to several hundred feet. At the great dam at the head of San Mateo Canyon, these cracks emerged from the lake and ran northward up on the hills for several hundred yards, breaking the fences where they crost. Plate 16A shows large lateral cracks of this description, already partly filled up, crossing a road that runs parallel to the fault at the upper end of Crystal Springs Lake. The main line of fracture is about 50 feet beyond the fence, and the cracks extend into the foreground at an angle of from 35° to 40° with the main fault-trace. The fence is pulled apart 40 inches in the two places which are shown in the photograph, and a total of 10 feet in ten different breaks in this locality, within a distance of 200 yards. Such lateral cracks as these were not noted on the southwest side of the fault.

The lateral cracks described above make an angle of 45° to the general line of the fault fracture. They appear to have been produced very much like the fracture lines in compression tests of building stones. There was evidently great pressure holding together the two faces along the fracture. A dam made of earth and rock divides Crystal Springs Lake into two parts. This dam crosses the fault-trace at right angles, and was offset but not badly cracked or injured by the movement. The fences that line the road were warped and their boards buckled thruout the distance across the dam. The earthquake rendered them too long for the distance from the hills on one side of the valley to those on the other. The inference is that a strong compression took place. The slicken-siding shown in plate 62A furnishes further evidence of compression. In the same way the heaving up of the sod into a long, raised mound, for most of the extent of the furrow, suggests lateral pressure. The formation of cracks a few inches to 2 or 3 feet wide in places along the furrow seems to contradict the theory of compression; but these are regarded as due to the irregular, crooked fracturing of the surface and the faulting of irregularities into juxtaposition with one another near the surface. The open cracks

were never found to be of great extent, but were usually followed by stretches along which the earth was heaped up into a mound, as if by being prest together. The surface furrow indicates that there was a zone of crushing some 2 or 3 or more feet wide. Where a similar cross-section of the fault is viewed from the opposite direction, no such face is exhibited on the northeast side, but instead a mass of crusht earth projecting beyond its former position.

Offsets on fences, pipes, dams, etc. — About a mile southeast from the point near Mussel Rock where the furrow was first noted as a clearly defined feature, the fault-trace passes thru the trough of a well-marked saddle. This feature is more accentuated than similar features at other points along this portion of the rift, tho many such are found. Southeast from this saddle there is recognizable in the topography a distinct line of former movement, lying east of the fault. No furrow follows the line continuously, but an occasional

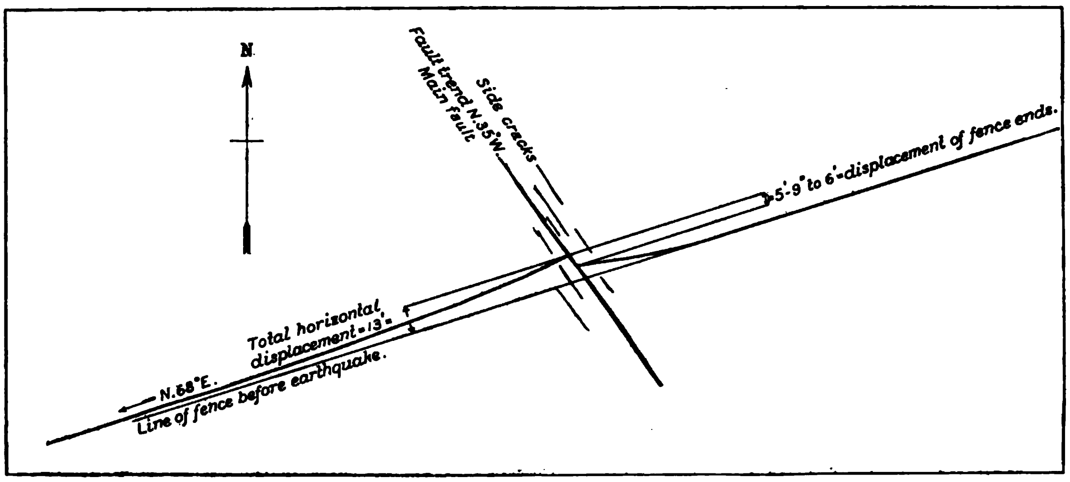


FIG. 29. — Offset fence southeast of Mussel Rock, showing distribution of deformation on either side of fault.

short fissure or crack runs along it for a little way. To the west of the place is a similar, but less well marked, topographic indication of a former movement. There is no evidence of any movement on this line at the time of the earthquake. At the point where the fault-trace crosses the road, less than half a mile farther on, the roadway and fence were broken, but the effects were so confused that the measure of the offset could not be determined. The apparent horizontal displacement was slight.

Still farther to the southeast, about 1.25 miles, the fault intersected a fence and not only caused it to be offset, but the intersection showed clearly the effect of the drag in the earth movement. The bearing of, the fence is N. 68° E., so that it is approximately transverse to the line of the fault. On the west side of the latter, the fence suffered a displacement to the northwest of 13 feet from its former position, and this displacement was effected by a bending or curvature in the fence line extending westerly from the fault for a distance of over 200 feet. On the east side of the fault, the fence was bent away from its former position, *in the same direction*, about 7 or 7.25 feet, the bent portion extending easterly from the fault-trace about 45 feet. The two ends of the fence were thus offset on the line of the fault only 5.75 to 6 feet, altho the total displacement was 13 feet. The displacement is shown diagrammatically in fig. 29. At a point 330 yards beyond this, on the Rift, the fault-trace was found to be confined to a furrow about 6 feet wide, passing thru a little trough between an outcrop of Franciscan on the west and a fine conglomerate (Merced) on the east.

Nowhere along this portion of the fault-trace between the slide at Mussel Rock and San Andreas Lake was there observed any definite evidence of vertical displacement. There was a hint of slight upthrow on the western side, but it could not be tested by measurement. There were, in general, furrows on either side of the main fault, at various distances up to 200 feet. Some of these were persistent for considerable distances.

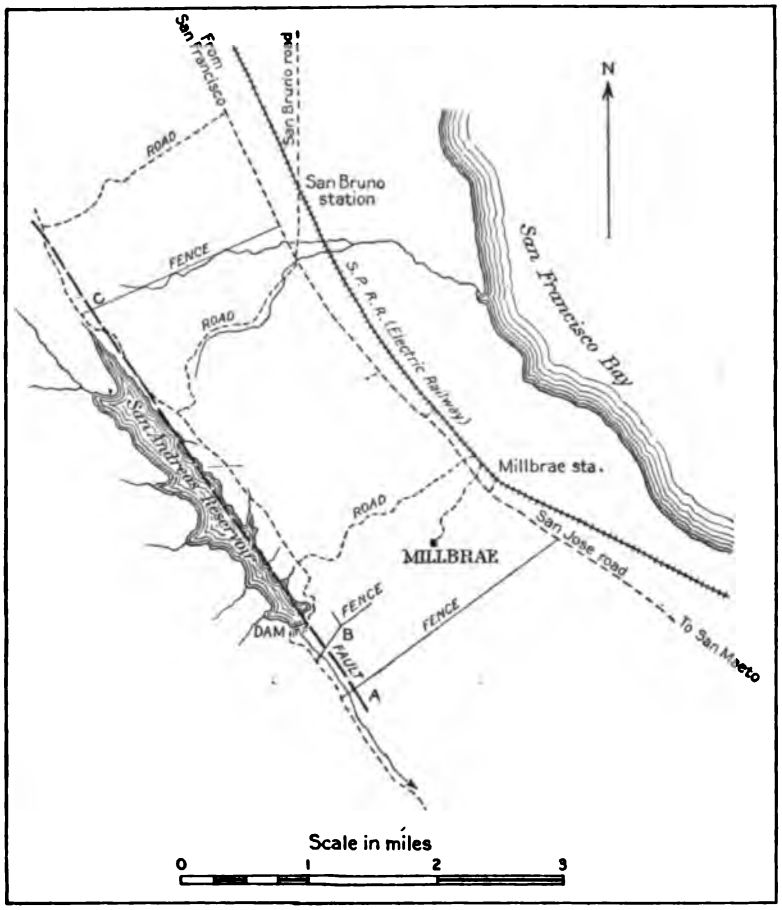


FIG. 30. — Index map showing positions of three fences, *A*, *B*, and *C*, the offsets of which are shown in figs. 31, 37, and 38.

About 2 miles from the upper end of San Andreas Lake the fault encounters the 30-inch, laminated, wrought-iron pipe of the Spring Valley Water Company, which prior to the earthquake conveyed the water from Pilarcitos Lake to San Francisco. The metal of the pipe is about 0.1875 inch thick and coated with asphaltum. The pipe is buried in the soil at a depth of 3 to 4 feet. The point of intersection is near Small Frawley Canyon. Here the course of the pipe swings from a northwesterly to a more northerly course, and the fault consequently intersects it at an acute angle. At the point of intersection, the pipe was obliquely sheared apart and telescoped upon itself, effecting a shortening of about 6 feet. The amount of the transverse offset involved in the shear was about half the diameter of the pipe. The portion north of the break was moved east and telescoped southerly. For 0.875 mile southeast of this point, the path of the fault lay on the northeast side of the pipe and nearly parallel to it, but a short distance away. About 220 yards southeast of the intersection, where the pipe, buried a few feet below the surface, ascends a rising slope, the pipe had completely collapsed for a distance of several

yards, due doubtless to the establishment of a partial vacuum within the pipe by the sudden withdrawal of the water from the arch in the pipe at the time of the shock, owing either to the leakage below, or the propulsion of the water induced by the shock. (See plate 60B.)

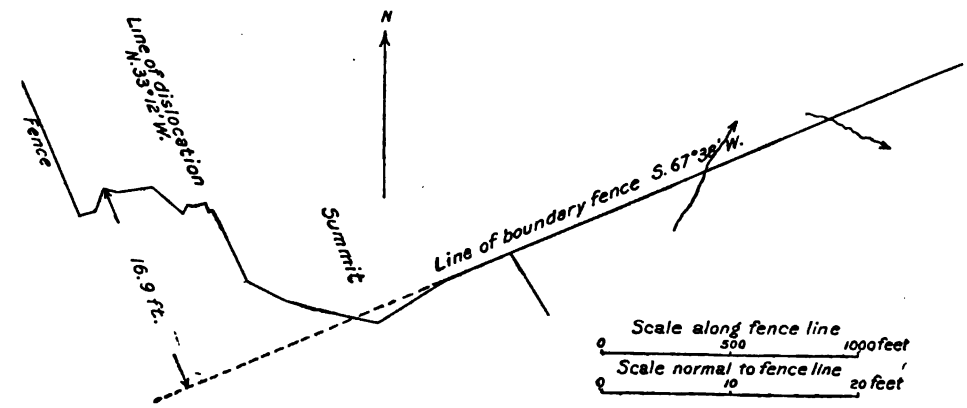


FIG. 31.—Fence *C* of fig. 30.

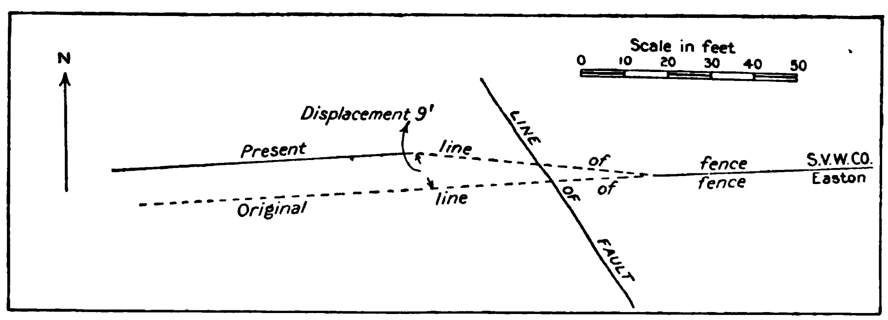


FIG. 32.—Dislocation of fence near San Andreas Lake. After H. Schussler.

At a point about a mile from the upper end of San Andreas Lake, the fault intersects a bend in the pipe at two places, and here again the pipe was telescoped. (See plate 60A.) The conditions at one of these intersections are thus described by Mr. Robert Anderson:

The pipe makes an angle of about 15° with the fault-trace, the end of the pipe on the north side of the fault running that much nearer the north. The ends of the pipe on opposite sides of the fracture were therefore thrust into each other. The furrow was at this place divided into several smaller ones, the disturbed zone covering an area of considerable width. The pipe was broken in three places within 100 feet. In one place it was telescoped 58 inches, as shown in plate 59B; in another 17 inches, and in a third, the one farthest north, 41 inches.

Near the head of the lake, the pipe was again intersected by the fault, with results described by Mr. Anderson as follows:

The pipe line runs almost parallel with the fracture, but slightly more to the west at this point, so that the acute angles made by the ends of the pipe with the furrow were in this case on opposite sides of the furrow to those in the two previous instances. In other words, the southeast end of the pipe was farther to the east than the southeast end of the

furrow. The movement was in the same direction as before, therefore a pulling apart of the pipe took place instead of a compression. There occurred two breaks in the pipe (see plate 59A), the main one at the crossing of the fault, and the other 150 yards away on the northeast side of the fault, but very near it, the pipe being almost parallel with it. At the main break, the pipe was pulled apart 59 inches, and at the other one 21.5 inches, making a total displacement of 6.666 feet. The pipe was not quite parallel with the fault and therefore there was a slight offset, at right angles to its direction, of 4 inches at the main break and 2 inches at the minor one, or a total of 6 inches. A fence which crost the fault at the main break is offset 6.5 feet. (Plate 60c.)

The index map, fig. 30 (p. 95), indicates the position of three dislocated fences which were surveyed by R. B. Symington, C.E. The fences are marked *A*, *B*, *C*. One of these fences, *C*, near the upper end of San Andreas Lake, is nearly normal to the trace of the fault, and its deformation extends over a zone 1,200 feet wide, the total displacement aggregating 16.9 feet. Here, as usual, the portion on the southwest side of the fault moved relatively to the northwest, but there was a distinct drag on the northeast side in the same direction. (See fig. 31.)

The offsets in three other fences southeast of San Andreas Lake are shown in figs. 32, 33, and 34 and plates 60D and 61B.

Thruout this 2-mile stretch within which the pipe line nearly parallels the fault-trace, the path of the latter is strongly marked by a prominent furrow in the sod, with the usual diagonal cracks and variable width. This furrow lies on the northeast side of the

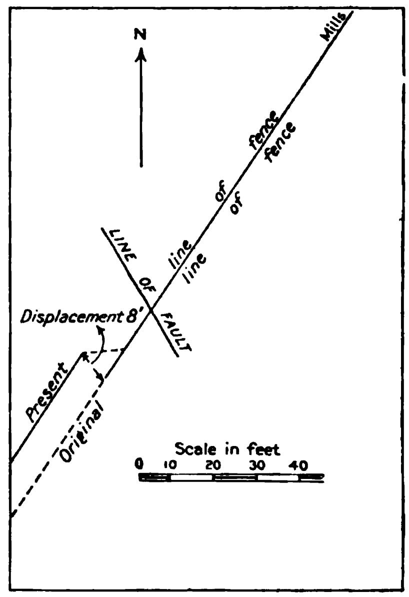


FIG. 33.—Dislocation of fence near San Andreas Lake. After H. Schussler.

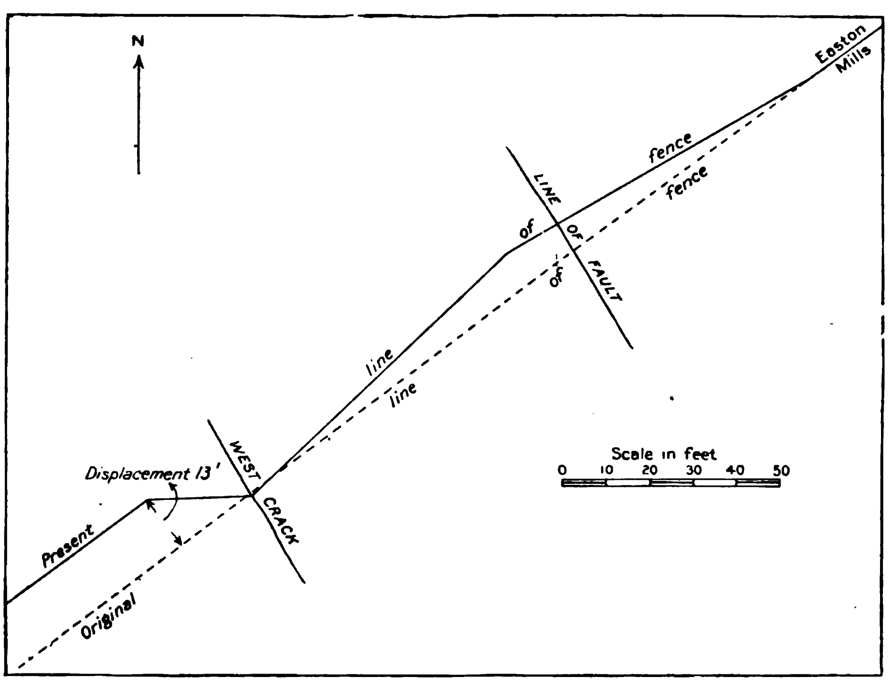


FIG. 34.—Dislocation of fence near San Andreas Lake. After H. Schussler.

lake for the first 0.875 of a mile of its length. It then enters the water (plate 61D) and follows the northeast side of the lake, a little distance from shore, to the San Andreas dam at the lower end of the lake. In this distance of nearly 2 miles, the fault-trace emerges from the water at a number of points where little capes project into the lake. The crossing of these capes by the fault-trace indicates that it follows a very straight course beneath the water of the lake. On the last of these promontories traversed by the fault, the main fault-trace has associated with it a number of auxiliary cracks. Between the main fault-trace and one of the diverging cracks, on the southwest side of the fault, is a brick and cement gate-well in connection with the tunnel which takes the waters from the lake toward Millbrae. This gate-well was circular in cross-section, the inside diameter being about 26 feet. The nearest point of the structure to the main fault-trace is within 5 feet.

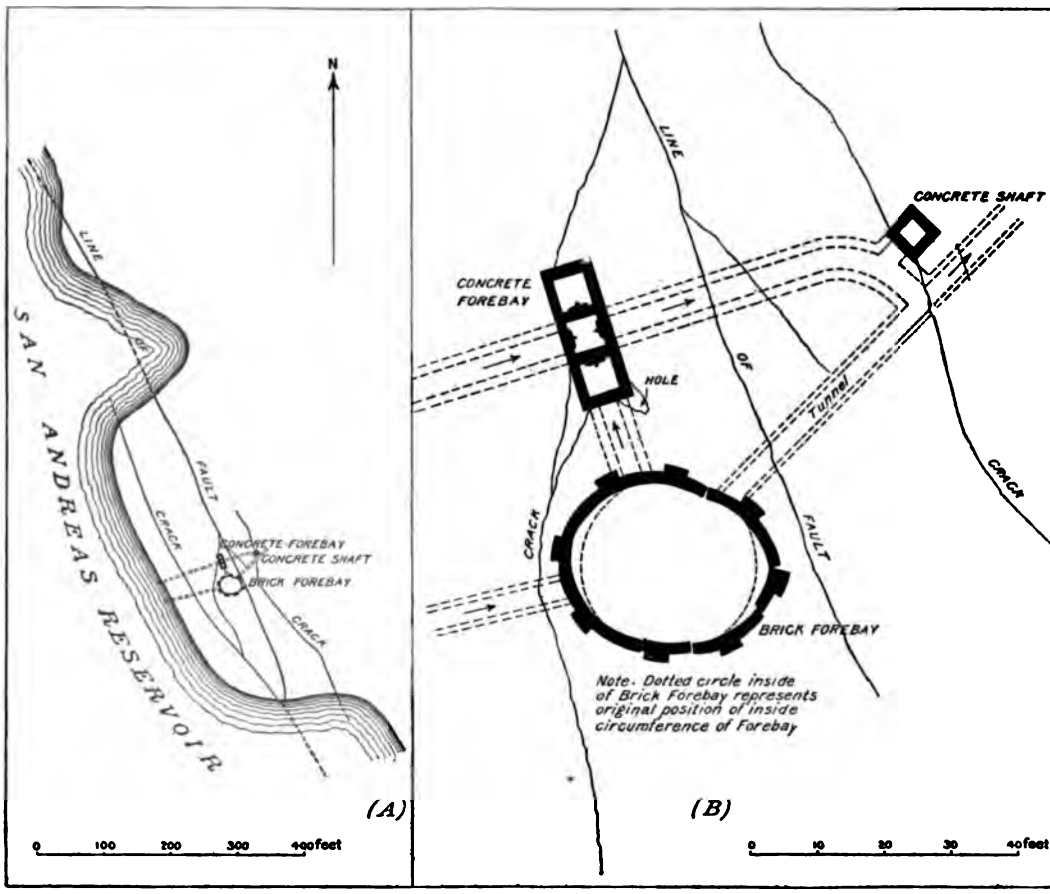


FIG. 35.—Main and auxilia y faults, San Andreas Lake. *A.* General Plan. *B.* Detail. After H. Schussler.

The walls are about a foot thick, and are strongly buttressed. As a result of the shock this gate-well was shattered and deformed so that it became oval in cross-section, the east and west diameter becoming 30 feet and the north and south diameter about 21 or 22 feet, as shown in the accompanying figure. A new concrete gate-well a few feet to the north, rectangular in cross-section and having three compartments, each 2.5 × 2.5 feet, was uninjured, altho on the line of the same branching crack. A concrete manhole 45 feet northeast of the damaged gate-well, also on an auxiliary crack, was similarly unaffected. (See fig. 35.)

At the San Andreas dam, the fault past thru a rocky knoll which serves as an abutment for the dam on both sides, the embankment being in 2 parts. The rocks were shattered and the road over the dam and the fence paralleling it were offset several feet in the usual direction. The ground here was traversed by several cracks, those on the south-

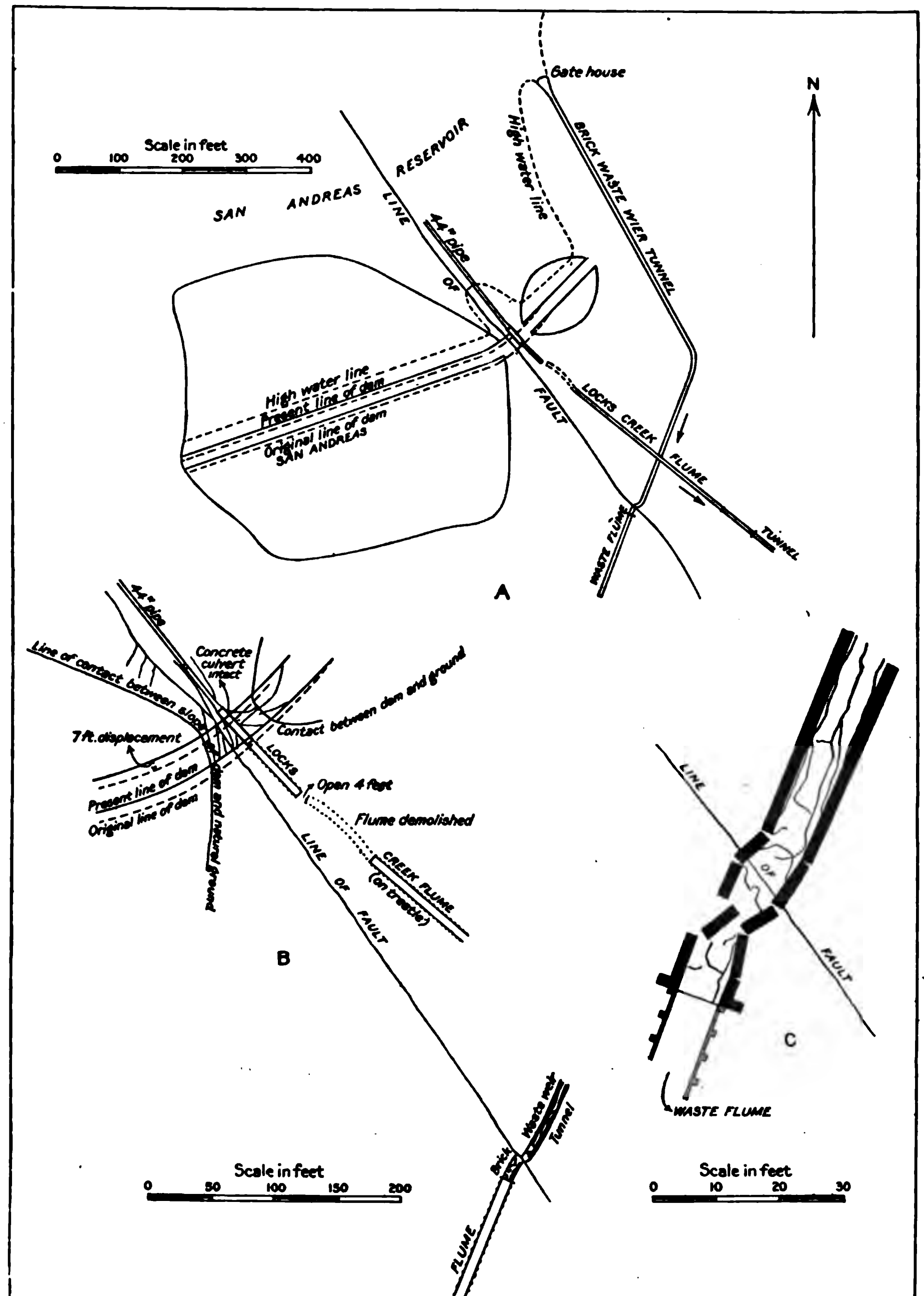


FIG. 36. — Intersection of San Andreas dam by fault. *A*. Plan of dam in two parts, with rock between. *B*. Relation of dam to waste weir tunnel. *C*. Detail of waste weir tunnel.

west side of the fault branching southerly from it and those on the northeast side branching northerly. Below the dam a heavy wooden flume on a trestle within 50 feet of the fault-trace was demolished for about 60 feet of its length.

About 125 yards below the dam the fault past thru the lower end of a massively built brick and cement waste weir tunnel. The inside diameter of the tunnel was about 7 or 8 feet and the walls were 17 inches thick. At the intersection of the fault within this structure, the latter was stove in and smashed in pieces for a distance of about 28 feet. The tunnel was offset about 5 feet. In the shattering of the brick work, the cracks and ruptures in no case followed the cement between the bricks, but broke across the latter; the cement and its adhesion to the bricks being stronger than the bricks themselves, altho the bricks were evidently carefully selected and of good quality. Several cracks traversed the tunnel longitudinally and obliquely to the northeast of the part that was demolished. (See fig. 36.)

About 550 yards below the San Andreas dam, the fault-trace crost a boundary fence between the estate of D. O. Mills and the property of the Spring Valley Water Company, causing an offset of about 10 feet. Here the deformation of the fence was distributed over a zone 300 feet wide in the direction of the fence, or about 250 feet in a direction normal to the trace of the fault. A survey of the dislocated fence made by R. B. Symington, C.E., is shown in fig. 37. Half a mile below the dam, the fault again crost the Pilarcitos pipe. A note by Mr. Anderson as to the conditions at this intersection is as follows:

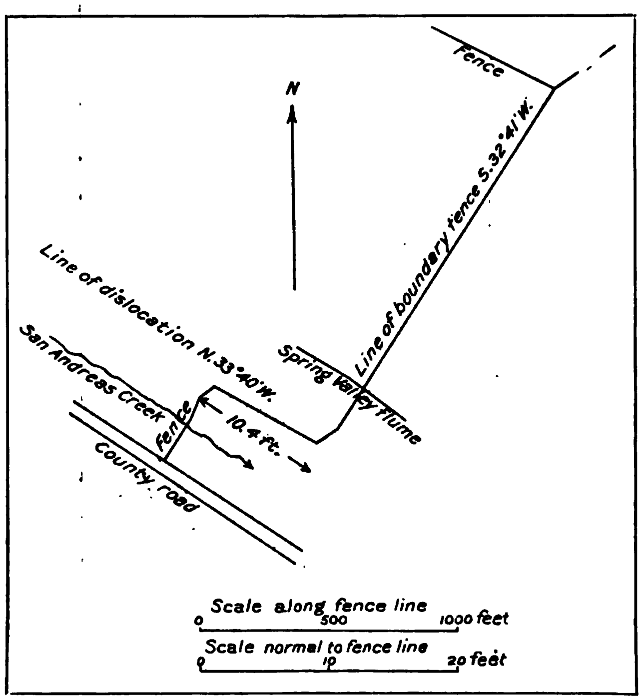


FIG. 37.—Fence *B* of fig. 30. Dislocated by fault.

It is a 2-foot pipe made of iron 1 inch thick. The fault broke it at an upward bend. An elbow at the bend was crusht by the compression and thrown down, while the two remaining ends were brought about 22 inches nearer together. At the same time they were faulted past each other a distance of 20 inches. The pipe runs N. 25° E., making an angle of 65° with the fracture, which here runs N. 40° W. The telescoping at this angle, being 22 inches, represents 52 inches of faulting.

In this neighborhood the fault crost a wire fence nearly normally, the line of which had been carefully established by a series of stone monuments. The fence marks the boundary between the estates of D. O. Mills and A. M. Easton. The deformation of the fence as shown in the accompanying diagram, fig. 38, from a survey by R. B. Symington, C.E., extended over a zone at least 2,200 feet wide. On the southwest side of the fault-trace, the fence was displaced to the northwest a distance of 9.3 feet, and on the northeast side it was displaced to the southeast 3.4 feet, making a total displacement of 12.7 feet and showing a slight drag close to the line of the fault. There were two parallel cracks representing the fault about 90 feet apart, and the chief displacement took place on the west crack.

About 0.625 mile farther southeast, near the upper end of Crystal Springs Lake, the fault crost another fence showing a displacement of 9 feet. About 0.25 mile southeast of this place, the fault crost the Locks Creek 44-inch pipe line. Regarding this intersection Mr. Anderson writes:

A. Rupture of 30-inch water-pipe by fault. Northwest of San Andreas Lake. A. C. L.

B. Thrust of 30-inch water-pipe by fault, northwest of San Andreas Lake. Amount of telescoping is 58 inches. A. C. L.

A. Offset in 30-inch water-pipe by fault. Northwest of San Andreas Lake. A. C. L.

B. Collapse of 30-inch water-pipe northwest of San Andreas Lake. R. L. H.

C. Offset of 6.5 feet in fence, northwest of San Andreas Lake. R. L. H.

D. Offset of 6 feet in fence between San Andreas and Crystal Springs Lakes. Per J. C. B.

A. Fault-trace where it passes into San Andreas Lake. D.

B. Offset fence near Crystal Springs Lake. R. A.

A. Exposure of slicken-sided fault plane near north end of Crystal Springs Lake. R. A.

B. Offset of road by main fault near Searsville reservoir. Per J. C. B.

Just above the northern end of Crystal Springs Lake, a 44-inch water main made of iron 0.125 inch thick runs up the hill from the lake valley in a direction about N. 28° E. This line is buried all the way under several feet of soil. The fault crosses it at the base of the hill, in its N. 37° W. course, thus making an acute angle of 65° with the pipe line. At the intersection of the fault and the pipe line, the heavy rivets of the pipe were torn out all the way around at a section joint and the two sections were jammed into one another a distance of 4 feet 4 inches. In addition to the telescoping of this pipe, a slight change in course was induced, so that the northeast end trended one or two degrees more toward the east than the other end. This was shown by the fact that the broken ends did not fit into each other squarely. There was no lateral displacement, the whole movement having been taken up by the telescoping, but there was a bending of the pipes at the point of the break, as mentioned. The main part of the pipe, at a distance from the fault, must have moved with the land. At the fault-trace there was a bend amounting to one or two degrees. Supposing the bowing to be simple, this amount indicated that the land must have carried the pipe the distance represented by the telescoping, or about 10 feet, within 300 to 500 feet

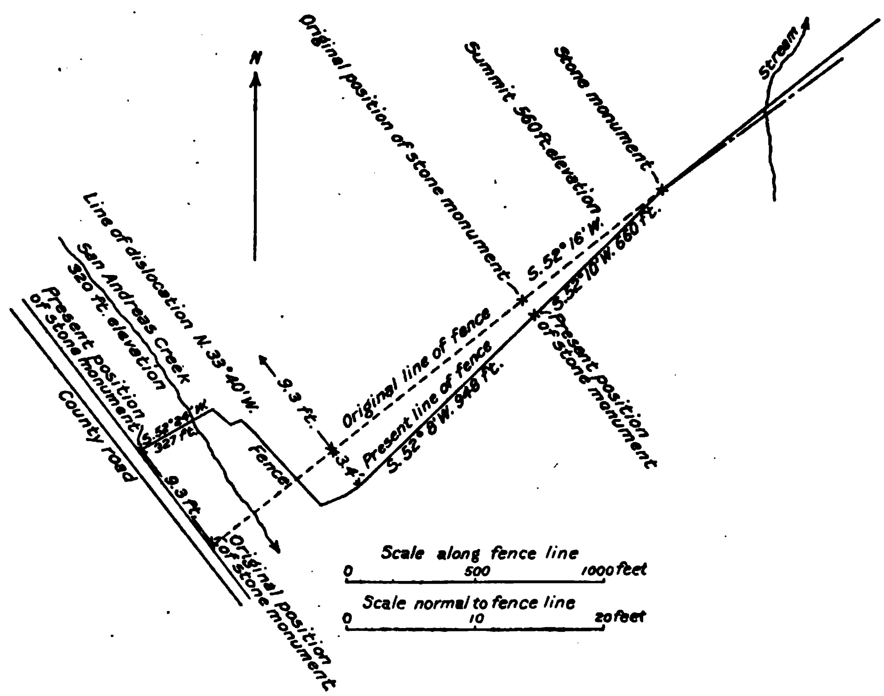


FIG. 38.—Fence *A* of fig. 30. Dislocated by fault.

of the fault on one side, and that beyond such a point the pipe must have preserved its normal course. As a matter of fact, this same pipe was broken on the northeast side of the fault about 400 feet further up the hill. The break occurred at the junction of 2 sections, the rivets having been sheared off and part of the rim torn away at the rivet holes. The ends were pulled apart 3.375 inches. Here the pipe resumed its former course, but owing to the slight amount of the pipe displayed by the excavation, it was impossible to see whether a return bend occurred or not. Beyond the break the direction was as before measured, approximately N. 28° E. No such break occurred on the southwest side of the fault. A crack was formed in the earth at right angles to the pipe for several yards on either side of the break.

The measurements of the engineers of the Spring Valley Water Company on the break and displacement of this pipe at the intersection above described by Mr. Anderson are given in the accompanying diagram, fig. 39.

About a mile southeast of the Locks Creek pipe line, the trace of the fault entered Crystal Springs Lake for the stage of water of April, 1906. At 2.5 miles farther

southeast, it crosses a small point projecting into the lake from the northeast side. Half a mile beyond it passes thru the dam between Upper and Lower Crystal Springs Lakes. This dam is now simply a causeway across the lake, the water on both sides standing at the same level. The dam was rendered superfluous except as a causeway by the construction of the great concrete dam at the outlet of the present Lower Crystal Springs Lake. The latter was uninjured by the earthquake, a careful examination having failed to reveal even a crack in the splendid structure.

Where the fault intersects the causeway dam between Upper and Lower Crystal Springs Lakes, the dam was dislocated and offset about 8 feet. (Fig. 40.) This displacement was well marked in the roadway across the dam and in the fences which parallel it. The fences on both sides of the road were broken and the boards were buckled and shoved over each other; the telephone wires crossing the lake sagged considerably, showing that the movement brought the poles closer together. The facts indicate, as previously stated, that, in addition to the offset of the dam along the line of the fault, there was a notable compression in the direction normal to it. Beyond this dam the trace of the fault is partly beneath the lake and partly skirts its southwest shore (for the water level of April, 1906), and finally leaves the lake on that side about 0.25 mile from its southeast end.

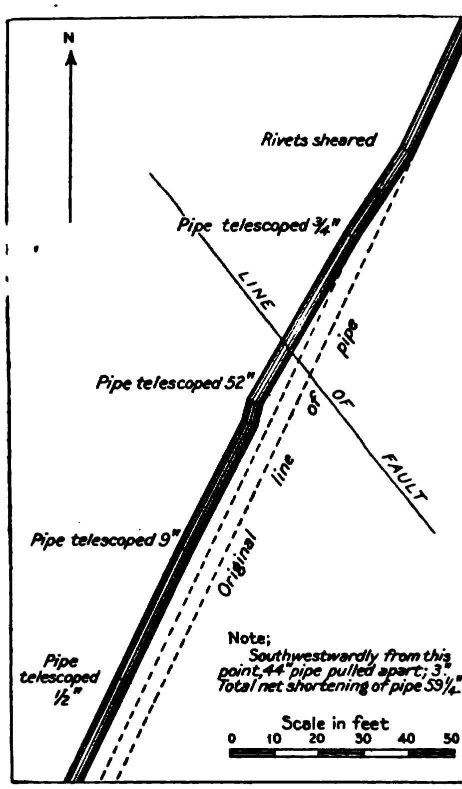


Fig. 39.—Intersection of fault and Locks Creek pipe. After H. Schussler.

Exposures of the fault-plane (R. Anderson).—In addition to the evidence given by fences and pipes, there is the displacement of land surfaces and actual exposures of the fault face at the surface. Examination of mounds, embankments, and shore lines crost by the rupture usually revealed a displacement of the surface, and an interruption of the old topographic outlines. In the case of mounds cut by the fracture, the displacement makes itself apparent in vertical scarps in consequence of the curved surfaces being faulted past each other. At the northwest face of a hillock, near where the furrow emerges from Crystal Springs Lake, the northeast side of the mound—the side away from the lake—has retreated relatively, leaving a portion of its lower slope in juxtaposition with the higher slope of the other side. A horizontal line across the exposed face would give the distance moved, provided no subsidence had taken place, which does not seem to have been the case. The distance could be only approximately measured, but it is at least 8 or 10 feet. A crack 2 to 3 feet wide and several feet deep separates the two walls locally. Looking at the other side of the same mound an irregular face several feet in height is exposed on the northeast side of the fault, the natural result of a longitudinal slipping. The faulting of raised surfaces after this fashion was discovered in various other instances. Large hills were crost only two or three times in this stretch of the fault. They were not so affected.

The banks of stream channels sometimes preserved evidence of the movement even more completely than did mounds. Almost every gully crost by the fracture suffered

a disjointing, resulting in a narrowing and bending of the channel at one point. The banks on the northeast and southwest sides of the fault were thrust past each other southeast and northwest, respectively. Usually the movement resulted in the crushing of the loose earth at the surface, while the roots of plants tended to hold it in place, so that the displacement was not evident in its full effect. An example where this is well shown occurs in the channel of a small stream running at right angles to the fault valley just north of the north end of Crystal Springs Lake. The banks of the gully were about 20 feet high. Where the fault crosses the southeast bank, the parts on either side of the crack faulted past each other horizontally, the result being a relative displacement of the northeast side of the fracture at least 8 feet toward the southeast. There is no vertical movement apparent. An escarpment is left exposed on the southwest side of the fault from top to bottom of the embankment. The material of the bank, plastic, argillaceous earth derived from weathered shale, was slightly moist at the time. The fault planes are closely apprest and the clay was left slicken-sided and lined with distinct horizontal striations. (Plate 62A.) The opposite bank of the stream gives evidence of a similar movement, but the loose earth was held by large roots and the displacement of the underlying earth was obscured. The two projecting faces of the opposite banks almost met, making the channel very narrow and curved.[1]

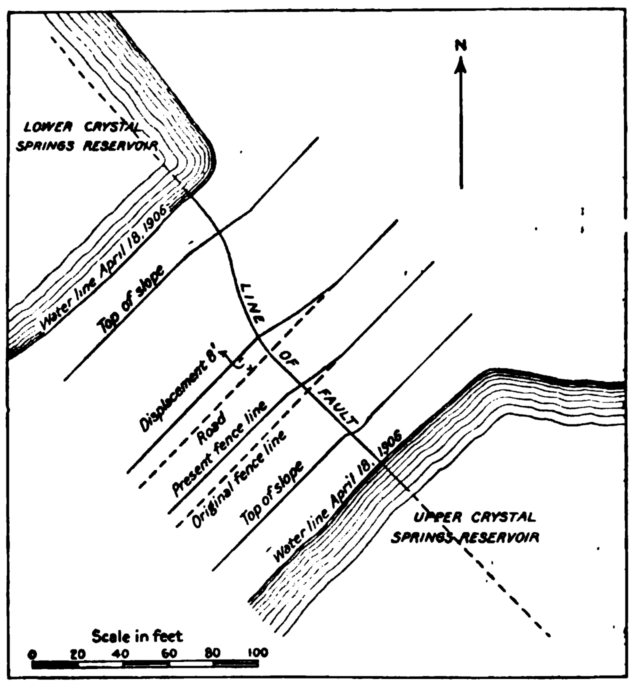


FIG. 40.—Map of fault-trace across old dam between Upper and Lower Crystal Springs Lakes. After H. Schussler.

A steep embankment of weathered serpentine and soil occurs at the southern end of San Andreas Lake, where it is crost by the fault. The zone of rupture is several feet in width and the broken material on the northeast side is shown projecting several feet beyond its previous position in continuity with the serpentine slope. A displacement of the shore line is observable at several places where the fault fissure enters the lake. Wherever cracks were opened, search was made for the disjointing of squirrel holes and other discrepancies due to shifting, but with rather unsatisfactory results. Roots, however, were found broken and displaced in accordance with the general movement as shown by other things. In general, the search for evidence in the separation of different zones of vegetation or of color in the earth, etc., failed to add anything of value to evidences of other kinds.

Vertical movement (R. Anderson). — No proof was found of a vertical movement along the fault line. Here and there occur small escarpments along the fissures, varying from a few inches to several feet in height. They were only local, however; they exhibited no constancy in the side of the fault upon which they appeared, and were invariably explainable either as fault exposures such as are discust in the previous paragraphs, or as

[1] The writer is indebted to Mr. C. E Durrell and Mr. F. D. Posey, of St. Matthews School, San Mateo, for the discovery of this interesting example of faulting.

due to settling of loosely accumulated or unsupported earth. For this reason no credence is given to the idea that an uplift or downthrow occurred along this part of the fault. This statement is based entirely on the evidence collected on the ground shortly after the earthquake and has nothing to do with the direction or amount of earlier displacement along this same fault-line. In some places an upward thrust seems to have taken place, as in the case of raising 7 pipes. This may, however, have been caused by wave-like movement in the ground near the surface or simply by the local heaving up of the ground as the result of compression.

CRYSTAL SPRINGS LAKE TO CONGRESS SPRINGS.

For our knowledge of the character and extent of the earth's movement on the fault for that portion of its course lying within the limits of the Santa Cruz quadrangle of the U. S. Geological Survey, or between Crystal Springs Lake and the vicinity of Congress Springs, we are indebted to observations made by Messrs. H. P. Gage, F. Lane, S. Taber, and B. Bryan, under the direction of Professor J. C. Branner. The notes of these gentlemen are preceded by a summary statement, and are arranged as far as possible in sequence from northwest to southeast in the following section:

Summary statement (J. C. Branner). — The fault-trace that follows the San Andreas Valley continues southeastward in a nearly straight line. Beyond Crystal Springs Lake, it passes thru the village of Woodside, the Portola Valley, crosses Black Mountain a mile southwest of the triangulation station, follows down the general course of Stevens Creek a distance of 5 miles, and thence, following the same general direction along the eastern slope of Castle Rock Ridge, passes off the eastern side of the Santa Cruz quadrangle near latitude 37° 10′. West of Stanford University it follows along the northeastern base of the mountains that lie between the Pacific Ocean and the Bay of San Francisco, but as it passes toward the southeast, it cuts into the range and leaves Black Mountain and Monte Bello Ridge on the northeast side, while south of Saratoga it keeps well within the mountains. A singular feature of the fault, as it appears at the surface, is that instead of following the bottoms of the valleys, it often skirts along the base of one of the enclosing ridges, as shown in the accompanying sections. (Fig. 41.) This is not an invariable rule, however.

It will be seen from the map, No. 22, of the isoseismal lines on the Santa Cruz quadrangle that there are several other faults within the area of the quadrangle, but evidences of movement at the time of the earthquake have been found only on this San Andreas fault-line, with the possible exception of slight movements along part of the Black Mountain fault. Cracks in the ground occur here and there almost all over the area covered by the sheet, but the cracks away from the San Andreas fault are due to incipient landslides or to the settling of loose or wet ground, and are not otherwise related to the more profound faults.

The movement that took place along the fault in this portion of its course at the time of the earthquake was almost entirely a horizontal one. At several places evidences were seen of vertical displacement, but further examination showed in many instances that the appearances were deceptive or due to local causes. For example, where the fault crosses the top of Black Mountain there was apparently an upthrust on the northeast side of the fault. But it was found later that a great wedge-shaped piece nearly half a mile across had settled on the southwest side of the fault, producing this appearance.

The direction of the horizontal displacement is uniformly a relative southeastward movement of the land on the northeast side of the fault. The amount of displacement varies in this area from near zero to 8.5 feet. This variation appears to be due to the character and condition of the ground. Usually ground that was wet and incoherent at

the time of the rupture yielded and was crusht so as to distribute the displacement thru the surrounding soil. In such places, but little or no horizontal thrust appeared at the surface. Where the land was well drained and the surface materials were dry, the ground held together better except along the fracture itself, and the displacement was more apparent. It seems highly probable, however, that, owing to the deep decomposition of the rocks and the frequent movements and fractured condition of the beds along the fault, the maximum displacement does not appear at the surface anywhere within the area of the Santa Cruz quadrangle. Nowhere has the fracture been found passing thru freshly broken beds; and in view of the antiquity of the fault itself, and the evidence of many movements upon it, such an exposure is not to be expected.

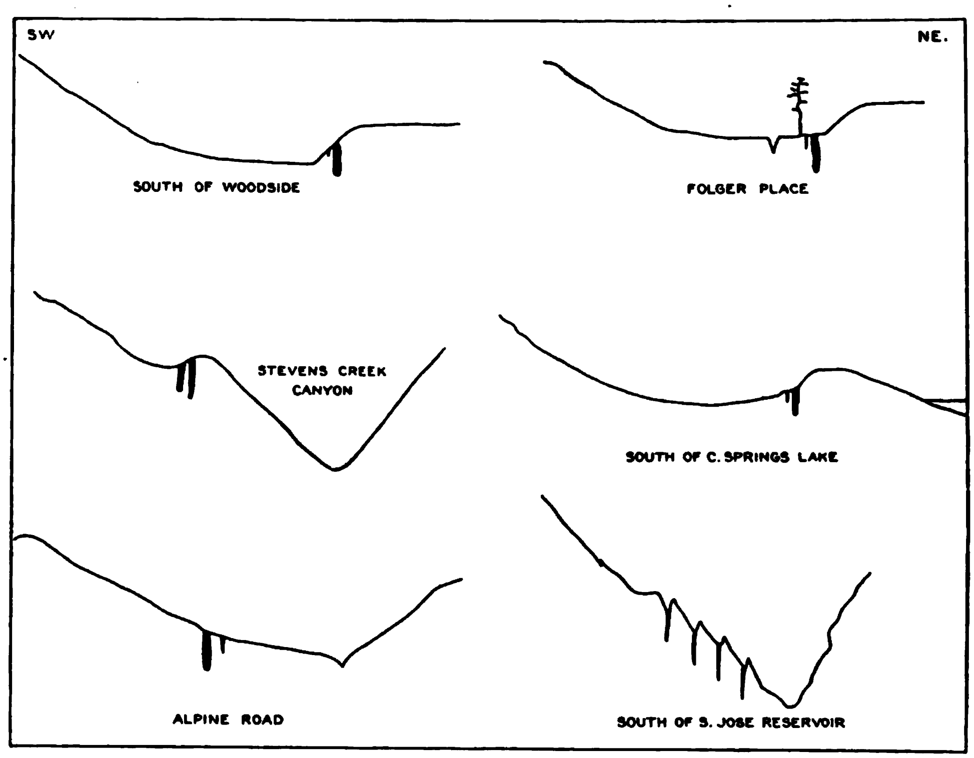


FIG. 41. — Profiles of Rift, showing relation of fault to slopes.

Crystal Springs Lake to Portola. — Southeast of the southern end of Crystal Springs Lake are numerous cracks along the line of the fault. One less than 0.5 mile from the southern end of the lake past directly under a house, the chimney of which had fallen, and the building had burned to the ground. (28, map 22.) About 100 feet southeast of the road near this house (29, map 22) a crack 1.5 feet wide in places runs approximately parallel to the road. The cracked belt adjoining is about 4 feet in width, the downthrow being about 6 inches on the northeast side, the lateral thrust about 1 foot on the same side, the northeast side moving southeast relative to the opposite side.

About a mile southeast of the lake are large cracks, running approximately north and south, in places 1.5 feet wide. At a point 2 miles southeast of the lake, a crack about a foot wide is crost by a fence running N. 53° W. (27, map 22.) The top wire of this fence was broken by tension during the shock, and the post nearest the crack was snapt off at the ground, the adjoining post being uprooted, and bent over in the same direction as the broken one. The posts are of split wood about 5 inches in diameter, and the wires

are 2-strand barbed wire. This belt of cracks continues for about 300 yards along the road. Near Woodside there was a 2-inch crack trending northwest-southeast, with an upthrust of about 2 inches on the northeast side. A crack 1.5 feet wide in places runs N. 23° W. across the road, entering Woodside village from the southwest, just west of the bridge, and in places shows an upthrust of about 2 feet on the northeast side. A small tree on this crack was uprooted in the western part of the village. On the King's Mountain road, southeast of Woodside, a large crack of the main fault-trace crost the road, and the fences on both sides were pulled apart. (See plate 62B.) No vertical throw was observable. About 200 feet west of the fault fracture were several smaller cracks parallel to it.

Further southeast, down the road toward Portola, the main fault-trace crosses the road just north of the creek and within 12 feet of a giant redwood. The ground was raised and crumpled across the road, and the cracks extend both up and down the stream from this place. In a cluster of young redwoods southeast of this road a board fence is bent out of line, and huge cracks opened among the roots of the trees. A wire fence was pulled in two and one of the posts split. In this cluster of trees the fault past thru and split a big redwood stump.

Two fences crossing the crack at right angles near 12 (map 22) had been thrown out of line, their northeast portions being moved southeast relative to their southwest portions. They had been given an offset of 8.5 and 8 feet respectively. (Plate 63B.) A large oak tree standing on the crack was uprooted, while branches were snapt on a big white oak tree just south of the fault line.

Northwest of Searsville Lake, about a mile, there is a belt of cracked ground 7 or 8 feet wide, one crack being 1 foot in width. The apparent upthrust was in some places 2 feet on the northeast side. At other places there is no change of level. On the Portola road, just southwest of the Searsville Lake, parallel cracks with a trend N. 43° W., some of them 1.5 feet wide, were formed across the road and extended into the marsh to the northwest and into the woods on the southeast. Where they crost the road, the fence boards were broken and the earth shoved up in ridges; the northeast side of the crack moved southeastward.

The main fault fracture passes thru the Portola Valley and crosses the public road in front of a small 1-story house southeast of the village store. Where the fault crosses the road, the fences on both sides were torn in two, and in the prune orchard south of the road the rows of trees were displaced in some instances about 2 feet. The cracks in the road were about 6 inches wide, approximately parallel, and running nearly north-south, while the direction of the fault line itself was about northwest-southeast.

About a mile beyond Portola, a crack, measuring 2.5 feet in width in some places, crost a field, the cracked ground spreading out for 10 feet at intervals. Wooden fences crossing it were broken, water pipes bent and pushed up to the surface of the ground, and a dead tree near the line of the crack was thrown down. There was an apparent upthrust of about 2 feet on its northeast side.

Road from Judge Allen's southward. — Between 3 and 4 miles southeast of Portola, many cracks were visible extending in all directions. Several showed an uplift on the east or northeast side, which is also the downhill side. Some cracks were from 4 to 5 inches wide, and had a vertical throw of nearly a foot. In other places the downhill side had been thrust upward, and pieces of the crust shoved as much as 4 inches over the uphill side. Near the top of the ridge, just before reaching the point where the trail branches off, a 4-inch crack running S. 63° E. showed a 4-inch upthrow on the northeast (downhill) side. Southwest of the ridge and about 100 feet below the trail, an old landslide dating back to some time within the past year, covers about 2 acres. Around this slide the ground appeared to have been much cracked recently.

Along this trail the direction of the cracks varied considerably. One an inch wide in places, elsewhere branching into several smaller ones, was traced for about 150 yards, chiefly along the crest of the ridge. Its direction varied from due east to southeast, and the upthrust on the west was sometimes as much as 3 feet. Going northwest down the crest of the ridge, numerous cracks crost in directions varying from southeast-northwest to northeast-southwest, several showing an upthrust varying from a few inches to a foot on the southwest side. At the foot of the trail, a large crack running down the center of the valley followed the road for about 100 yards, then cut across the fields. In places the crack was 2 feet wide, but in other places a ridge 3 feet high had been raised beside the road, and there were many parallel cracks within 50 feet of either side. There were upthrusts and downthrows, some as much as 1.5 feet, but the total change of level seemed to be nil.

Alpine road. — A fault branches from the main San Andreas fault in the Portola Valley and crosses the Alpine road just where the Portola road leaves the latter. At this fork several cracks were formed at the time of the earthquake. A water pipe 2 inches in diameter was buckled and lifted out of the ground here, and farther along the Portola road this same pipe was pulled apart. Following southward along the Alpine road, the next evidence of disturbance by the earthquake was where the main fault-trace crosses the road 0.75 mile south of where the Portola road forks. Here the road was so badly broken and cracked that it was not possible to ride or drive across the fracture until the place was repaired. (Plate 63A.) The fracture followed along the south side of the road for a distance of 300 feet, tearing up the bank with cracks, some of which were a foot or more across. Where the road bends toward the south, the fracture crost to the north side of the road, making cavities several feet deep. These cracks continued toward the northwest thru the underbrush, pulling apart a barbed wire fence and leaving many well-marked furrows thru the adjoining fields. About 30 feet north of the road, a white oak, somewhat weakened by decay and fire, was jerked off by the violence of the shock. To the southeast the fault-line is traceable by a well-marked furrow thrown up in the fields. Where the fracture crosses the Alpine road, there appears to have been an uplift of about 2 feet on the northeast side of the fault. This appearance may be due to the settling of a part of the ridge of incoherent materials to the south, or it may be due to the lateral thrust along a sloping surface.

Black Mountain. — The great mass of Black Mountain lies between the San Andreas fault and a branch fault (Black Mountain fault) which, starting in the Portola Valley, crosses the Page Mill road on the north side of the mountain about a mile south of Clarita vineyard. This area between the faults was badly shattered by the earthquake, tho it is not clear whether the abundant cracks found over the surface are to be attributed to the boldness of the topography or to the crushing of the wedge-shaped end of the fault block. Several days after the earthquake, 345 cracks, large and small, were counted along the county road (Page Mill) in a distance of less than 3 miles between these faults. These cracks ran in every direction, and some of them were clearly attributable to local topography, while others cut thru the mountains in apparent disregard of the topography.

The main fault-trace crosses the Page Mill road in a topographic saddle near three frame houses. The displacement occurred along two parallel and well-defined cracks some 30 feet apart. These cracks can be traced across the fields on both sides of the road. Toward the northwest they converge until they are only a few feet apart. Where they crost the road, the fracture was not a single clean-cut break, but made up of a series of small short cracks from 3 to 5 inches across, parallel with each other and "splintering" across the general direction of the fracture. The fences on both sides of the road were displaced about 3 feet, and there was an apparent drop of 18 inches on the southwest side of the fault. The horizontal displacement showed the northeast side to have moved

relatively toward the southeast. The apparent vertical displacement seems to be deceptive, or rather, it appears to be due to the settling of a wedge-shaped mass on the southwest side of the fault. The south side of this mass was indicated by a crack about 300 yards farther south along the road where a crack showed a drop of several inches on the northeast side. On the Monte Bello Ridge, a mile southeast of the Black Mountain triangulation station, there were a few inconspicuous cracks, without any uniformity of direction. Just south of the triangulation station, the cracks were more conspicuous; one of them was 200 feet long, and had a bearing of N. 13° W. At and about Hidden Villa, a small ranch in the deep valley 2 miles northwest of Black Mountain triangulation station, there were no cracks in the low ground, even where they were expected, as this is on the line of the Black Mountain fault that crosses this region from the direction of Portola.

Page Mill road. — In following the Page Mill road up Corde Madera Creek from Mayfield, the first noticeable trace of the earthquake was a crack crossing the road due east and west, its width varying from 0.5 to 1 inch. Wagon-tracks showed a lateral displacement of 1 inch, the north side of the crack having moved west, relatively to its south side. This crack was traced a short distance into the fields beside the road, where it disappeared. Several smaller cross-cracks intersected it at intervals. There was no apparent vertical displacement. About 100 yards farther south were 3 smaller cracks varying from 0.25 to 0.75 inch in width. One ran N. 53° W., and another N. 23° W. The latter, being only 8 feet from a culvert crossing under the road, appears to have been deflected by this from a course running more nearly east. Here again was no evidence of vertical throw. Going on up toward the Alpine road from this point, more and more cracks were found, running approximately east and west, with the exception of several north and south ones where the road ran closely parallel to the stream. Less than a mile from the first crack, groups of cracks were accompanied by small slides of dirt from the hill to the west of the road, and farther on from the bluff to the east of it. The cracks ran nearly parallel with the axis of the branch valley lying northeast and southwest. Farther up the road, large cracks began to appear among smaller ones running parallel. The first of these was 2.5 inches across and ran S. 13° E., with a downthrow of 1 inch on the east side, and could be traced from 50 to 100 feet on either side of the road. For a mile farther up the road, the cracks became so numerous and complicated that it was impossible to map any individual ones. They intersected and ran in all directions, and were all of varying widths, the largest seen measuring 8 inches across. The size of this crack, however, was probably partly due to its position on the side of a hill. The larger cracks could be traced for several hundred feet. In some places crushing had taken place, and the layer of macadam on the road had been humped up and broken. In this same area are many small landslides, some large enough to cover the road; one has occurred since the earthquake.

Stevens Creek. — Following the road from the junction of the Castle Rock Ridge road with the road from Stevens Creek to Boulder Creek toward Stevens Creek, small cracks appeared crossing the road in a direction of N. 1° E. Further east nearer Stevens Creek, the road was badly broken up by the land sliding in two directions, N. 18° W. and N. 47° E. All along this region cracks varying from a fraction of an inch to 2 inches in width, and running from N. 43° W. to due north and south, appear every 10 feet or more, showing a badly broken-up area. Here and there such cracks resulted in landslides from the bank to the road. A crack about 2 inches wide ran N. 53° W. for some distance above the house, at the junction with the Stevens Creek road. On the Stevens Creek road, just after leaving the Saratoga road, there were cracks every 20 or 30 feet, running in the same direction, about N. 43° W. A mile and a half northwest of the place where Stevens Creek turns northeast, a strip of ground 2 feet in width and about 100 yards long had been broken up, with a downthrow of about 6 inches on the west side. The cracks ran N.

A. Offset of Alpine road 5 miles west of Stanford University. Per J. C. B.

B. Offset of 8 feet in fence on Folger ranch, near Woodville. Per J. C. B.

43° W. From here northwest the disturbance continues in the same general direction. A number of breaks often occurred together, arranged as steps, in each case the downthrow being on the east side and measuring about 4 inches, the direction varying from N. 33° W. to N. 3° W. Following the Stevens Creek road on down toward Congress Springs, several landslides were noted, mostly small ones due to caving in of the banks of the creek. Just west of the springs the road was badly broken, twisted, and shoved up in places, the downthrow being first on one side and then on the other. In some places along the bank the west side projected 2 inches farther than the other, while the fence showed an offset of 2 feet. The large stone bridge across the creek appeared intact, but west of it a large patch of ground had slipt down 2 feet.

South of Congress Springs. — Near and northwest of the reservoir 2.5 miles southeast of Congress Springs, fissures from 4 to 6 feet wide ran nearly north and south, and past thru the earthen dam at the northwest end of the reservoir. (Plate 64A.) The intake pipes at the south end of the reservoir were disconnected, and the escaping water undermined a part of the southern dam of the reservoir. This reservoir is in a topographic saddle and has dams at both ends. The fault-trace passes thru this saddle. Where the bottom of the reservoir was exposed by the escape of the water, cracks of the fault-trace were exposed in the mud. Fences crossing the fissures showed but little displacement; the displacement moved the northeast side toward the southeast, relatively. The hills southeast of the reservoir have steep slopes of from 20 to 50 degrees. The cracks follow the east-facing slopes and the east side of these cracks had raised about 6 or 8 inches. Southeast of the reservoir the chimneys and water-tanks were down.

CONGRESS SPRINGS TO SAN JUAN.

Mr. G. A. Waring, under the direction of Prof. J. C. Branner, studied the displacement along the fault from the vicinity of Congress Springs to its southern end near San Juan. The following is an account of the phenomena observed by him:

Cracks and displacements along the fault-trace (G. A. Waring). — Starting at the upper reservoir about 2 miles south of Congress Springs, the fault-trace was followed to its southern end near San Juan. From the upper reservoir, thru which the fault past, cracking the dams at each end, a fairly continuous series of cracks a few inches wide runs down the southwest side of Lyndon Creek about 2 miles to Mr. Edwards' place, "Glendora." Thruout this distance the individual cracks run S. 3° to 13° E., while the line as a whole trends S. 33° E. The relative movement of the northeast side of the fault is from 14 to 20 inches southeast. From Glendora the fractured zone becomes wider and not so distinct. The lower reservoir is slightly cracked and several fissures appear near it, but the main line of fracture seems to be nearly 0.5 mile west of it, showing in two or three cultivated fields. The whole ridge west of the reservoirs was severely shaken, however, for cracks 4 or 5 inches wide opened near Grizzly Rock and several large slides occurred in its neighborhood. One water-pipe running north and south on the Beatty place was broken, while one trending east and west was unhurt. No cracks were found crossing the ridge between Grizzly Rock and White Rock. The cracks were next found on the road about a mile east of B. M. 2135 of the U. S. Geological Survey, but they do not show in the vineyard to the southeast. On the ridge road, about 5 miles northwest of Wright Station, the fault again shows slightly in a few 2-inch cracks bearing S. 3° E., with a slight relative movement of the east side toward the north. Going down the slope from here to Wright, the cracks rapidly become larger.

At Patchin, 3 miles west of Wright Station, there are fissures over a foot wide trending mainly in the direct line of the fault (S. 33° E.). Several stretches of numerous small

cracks alternating with a few long, continuous fissures, mark the course from Patchin to Wright Station. Thru the Morrell ranch it is especially evident. (See plate 64B.) At Wright Station the movement is well shown in the railway tunnel. (Fig. 42.) This tunnel runs southwest, and about 400 feet in from the eastern end of it there is a nearly vertical slicken-sided plane, showing a shear movement of 5 feet. Apparently the southwest side moved northwestward. Between Wright and Alma, the railway track was badly bent in places (see plate 107A), but the ground did not crack noticeably. It seems to have been subjected to compression, for 7 inches had to be cut from the rails when the track was repaired. A large landslide also occurred close to Wright Station, partly damming up the stream. The fault past a little west of Wright, tearing up the public road at several places (plate 65A), especially at the blacksmith shop, near Burrell Schoolhouse. Sulfurous fumes are said to have risen from this crack for several hours. From this place the cracks run up over the ridge just west of Skyland. Large fissures show in the orchards and fields on the eastern side of the ridge, but are not so evident on the western slope. Here, instead, great landslides occurred, and redwoods were snapt off or uprooted. Thru the timbered region from Skyland to Aptos Creek, the course of the fault-trace is marked almost its entire length by a swath of felled trees, true fault fissures being found at only two places. On the northern side of Bridge Creek Canyon there are typical cracks from 1 to 8 inches wide, and here also occurred a great landslide which buried the Loma Prieta Mill. The second place where fault fractures are found is on the ridge between Bridge and Aptos Creeks, where there are well-defined fissures up to 18 inches in width, trending S. 3° E., with a downthrow of the western (upper) side of from 2 to 6 feet, and a relative movement of the east side a few inches toward the south. The cracked zone is about 50 feet wide. Great slides on both sides of Aptos Creek have almost made a valley of the canyon for fully 0.75 mile. Following across the ridges and canyons, the discontinuous line of slides and sinks in upland marshy places marks the course of the fault-line down into the lowland.

The road at Corralitos is said to have been slightly cracked, and in the low hills between Valencia and Corralitos a few cracks were found; but the fault evidently runs fully 0.5 mile east of Corralitos. The mountain roads east and northeast of Corralitos were rendered impassable by landslides and by the bridges being injured. Crossing the road near Hazel Dell Creek is a band of small cracks 35 yards wide, trending S. 3° E. The fence on either side is not displaced, but the posts lean 30° to the southwest. About 0.25 mile farther northeast the stake fence on the northwestern side of the road is moved 10 inches out of line, and the ground just beyond has sunk a few inches. The fissures appear to die out in the marshy land west of Wm. McGrath's house, and they begin again a mile eastward, halfway up the slope. Thru this upland meadow region is a series of slides and sinks gradually rising in elevation. At a small ravine, fissures again appear and follow up it (S. 33° E.) for 0.25 mile, mainly as a great furrow from 2 to 6 feet wide. Three ponds near the divide lie directly in its path, but the cracks are only a few inches wide here. Thru the grain fields beyond they are not very evident until at the divide between the steep slope to the Pajaro River and the gentle westward drainage. Several cracks a foot or less in width show on the ridge, but the fault seems to set off about 100 yards to the northeast and to consist of east and west cracks, having loosened the whole slope for nearly a mile northward of Chittenden, causing great landslides. The fault-line crosses the Pajaro River at the railway bridge at Chittenden. The movement is shown by the disturbance of the concrete bridge piers. (See plates 17A, 65B, and fig. 43.) Thence straight across the low hills and fields on the opposite side of the river a line of cracks extends, passing 0.5 mile west of Mr. Canfield's house, "just where the earth cracked 16 years ago." This crack crosses the Sargent-San Jose road a mile north of San Juan,

A. Reservoir in saddle south of Saratoga traversed by main fault. D.

B. Offset in fence at Morrell's ranch, above tunnel at Wright station. This particular displacement was not found in tunnel. G. A. W.

A. Offset in road near Wright. G. A. W.

B. Steel bridge over Pajaro River, near Chittenden, dragged from its abutment 3.5 feet. Compare Fig. 43. A. C. L.

as a single fissure 3 inches wide, trending S. 53° E. In the lowland to the southeast there is little evidence of the fault, but crossing at right angles the county road running north and south about a mile east of San Juan, is a band of small cracks 15 feet wide, causing the road to sink 8 inches and making a marsh of the field beyond. This is believed to be the southernmost point of the recent opening of the fault. No trace of it could be found where it would have crost roads beyond, nor were other cracks found or reported in this neighborhood. The disturbance affected the banks of the Pajaro River from Chittenden to Sargent, causing a cracking and sloughing of the banks into the stream but not a settling of the stream bed. The San Benito River was similarly shaken for about 3 miles up from its junction with the Pajaro. Cracks are also noticeable all along the Riverside road wherever it runs close to the river bank. The damage to the concrete abutments of the county bridge across the Pajaro River is due to this crowding in of the alluvial banks of the stream.

The tunnel at Wright Station (E. P. Carey). — Mr. Everett P. Carey reports that he made an examination of the tunnel at Wright Station soon after the earthquake, and again on February 17, 1907. The result of his observations is incorporated in the following memorandum:

The length of the tunnel is 6,200 feet. Its direction is S. 48° 24′.5 W. A fissure crost the tunnel 400 feet from the northeast portal, along which there was a lateral displacement of 4.5 feet. The movement on the southwest side was northerly with reference to the northeast side. Nothing of this fissure can now be seen, as the tunnel along that part has been excavated, the walls timbered and entirely obscured from view. My description rests on my examination soon after the earthquake, before any work had been done. The strike of this fissure is N. 52° W., making an angle of 80° with the trend of the tunnel, and it dips at an angle of about 75° to the west. The walls of the fissure were well smoothed and slicken-sided, but I did not determine the direction of the striæ. Specimens from this fissure indicate that the fault occurred in sandstone, and that much movement had already taken place along the same fault in apparently a variety of directions. Specimens secured at the time have changed from a damp, sticky, clay-like mass to a relatively dry, hard, and crumbled condition. Streaks of light-colored sandstone occurred in this dark attrition material.

The damage to the tunnel itself consisted in the caving in of overhead rock; the crushing in toward the center of the tunnel of the lateral upright timbers, and the heaving upward of the rails, due to the upward displacement of the underlying ties. In some instances these ties were broken in the middle. In general the top of the tunnel was carried north or northeast with reference to the bottom. This seems to be the prevailing condition in the exposed part of the tunnel not yet repaired.

I examined with particular care the walls of the tunnel at several points where the damage to the timbers appeared to be greatest, more especially between 1,400 feet and 2,200 feet in from the opening at Wright. At each place I found several fissure lines running somewhat irregularly, but in general parallel to the fissure already described 400 feet in from the entrance at Wright. These fissures all contained more or less attrition material. Three of them I had an opportunity to examine better than the others. In each case two distinct sets of striæ were found, one set vertical and the other set horizontal. The horizontal set was clearly more recent than the vertical set, and to all appearances might have been formed the day before. The three slicken-sided faults mentioned were the only ones that lookt as if recent movement had occurred. The rocks in the tunnel look like sandstones and jaspers of Franciscan age. According to the evidence, so far as it went, the whole of the top of the mountain is fissured thruout in such a way that a large movement could be distributed among several fissures and thus account for a relatively slight motion along any one fissure. The measuring of any minor movements in the tunnel would be difficult because of the caving in of the rocks at such points. It would seem, too, that such movement could occur without materially altering the line of the tunnel at that point, so far as the timbering is concerned.

As far as learned no recognized fissures or faults have been crost by the workmen thus far, except the one 400 feet from the northeast portal. Nothing corresponding to the fissure passing Morrell's house has yet been found in the tunnel.

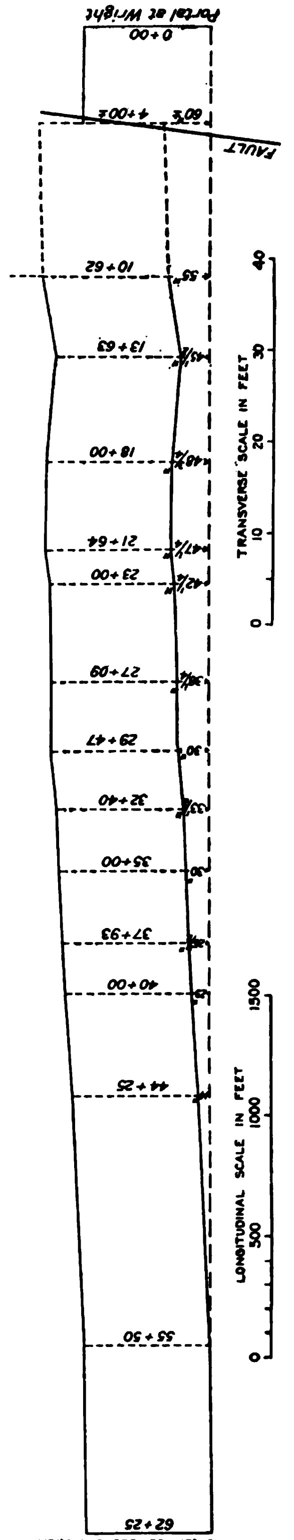


FIG. 42.—Tunnel at Wright Station, showing distribution of deformation.

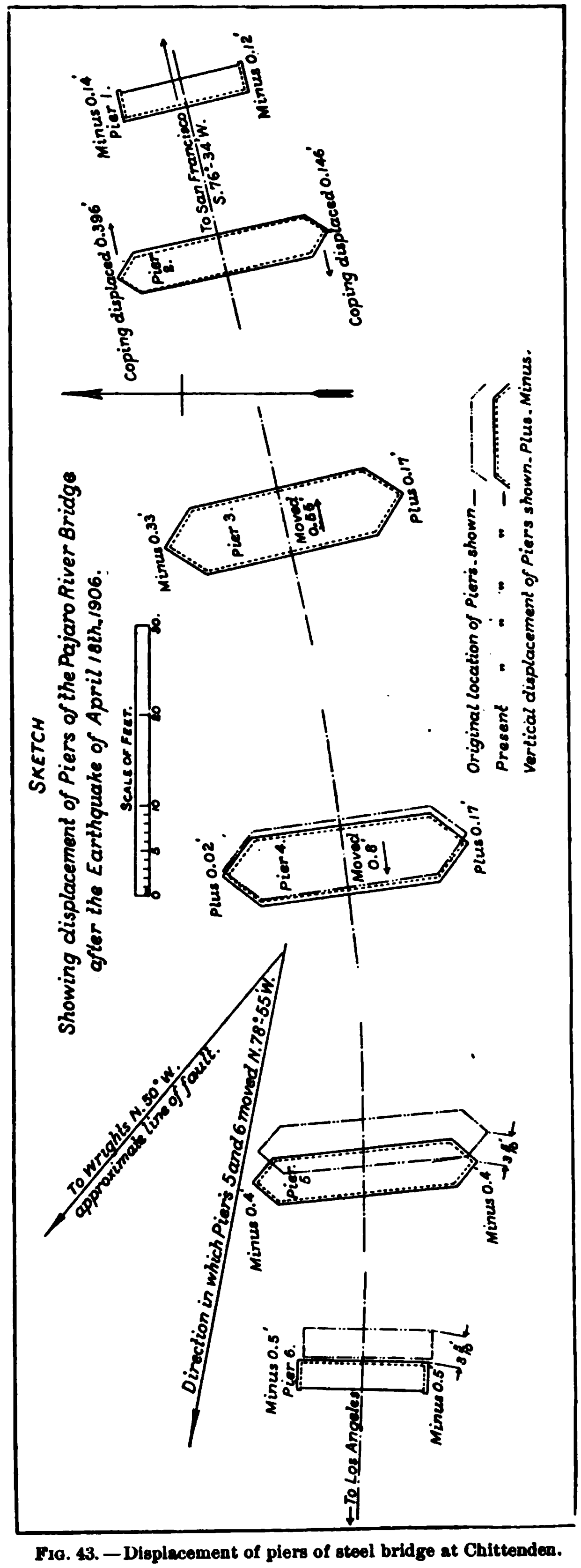


FIG. 43.—Displacement of piers of steel bridge at Chittenden.

Engineers' measurements of displacement. — The reconstruction of the tunnel at Wright Station necessitated an instrumental survey of the displacement in so far as it immediately affected the structure. The results of this survey have been placed at the disposal of the Commission by Mr. J. D. Matthews, assistant resident engineer in charge of the work. The plot of the survey is given in fig. 42. The plot shows that, while the tunnel is traversed by only one fault fracture, at a distance of about 400 feet from the northeast portal the deformation has been distributed over a distance of nearly a mile. This deformation of the tunnel, or its departure from a straight line, is measured from a line drawn from the northeast portal to a point on the same side of the tunnel 675 feet in from the southwest portal. It indicates a bending of the ground to the northwest in the direction of the relative displacement on the southwest side of the fault. That is to say, the bending is in the opposite direction to that which would be characteristic of the drag of a fault. A possible explanation of this phenomenon is that the ground pierced by the tunnel was in a state of excessive elastic stress, even at the time the tunnel was constructed; and that the relief effected by the rupture rendered resilience operative and so caused the ground to be flexed in the sense opposite to that of a drag. The nature of the deformation of the ground on the northeast side of the fault is not yet known. It may be here mentioned, in regard to the effect of the fault upon the steel bridge at Chittenden, that, in addition to the cracking and displacement of the supporting piers, as noted by Mr. Waring, the distance between the abutments was lengthened about 3.5 feet, according to measurements supplied to the Commission by Mr. J. H. Wallace, Assistant Chief Engineer, Southern Pacific Company. and illustrated in the accompanying diagram, fig. 43.

GEODETIC MEASUREMENTS OF EARTH MOVEMENTS.[1]

By John F. Hayford and A. L. Baldwin.

GENERAL STATEMENT.

The Coast and Geodetic Survey has done much triangulation in California to serve as a control or framework for its surveys along the coast and other surveys. The results of all the triangulation, south of the latitude of Monterey Bay, together with the primary triangulation to the northward, have already been published.[2] In 1906 the results of the triangulation in California, from the vicinity of Monterey Bay northward, were being prepared for publication. The reports from various sources in regard to the effects of the earthquake of April 18, 1906, indicated that there had been relative displacements of the earth's surface of from 2 meters (7 feet) to 6 meters (20 feet) at various points near the great fault accompanying the earthquake. These were relative displacements of points on opposite sides of the fault and had been reported along all parts of the fault for 185 miles, from the vicinity of Point Arena, in Mendocino County, to the vicinity of San Juan, in San Benito County.[3] The average relative displacement was said to be about 3 meters (10 feet). Displacements of that size would so change the relative positions of points which had been determined by triangulation and so change the lengths and directions of the lines joining them that the triangulation would no longer be of value as a means of control for accurate surveys. The value of the triangulation could be restored only by repeating a sufficient amount of it to determine definitely the extent and character of the absolute displacements. It was, therefore, decided to repair the old triangulation, damaged by the earthquake, by doing new triangulation.

If the displacements of a permanent character had occurred in a narrow belt only, close to the fault, but a few triangulation points would have been affected. The available evidence, however, indicated that the movements probably extended back from the fault for many miles on each side, and that the new triangulation necessary for repair purposes must, therefore, cover a wide belt.

The new triangulation to repair the damage was completed in July, 1907. In addition to serving this practical purpose, it has shown the character of the earth movements of 1906, which were found to extend back many miles on each side of the fault. These are very interesting results from a purely scientific point of view. Moreover, there came to light, during the study of the movements of 1906, entirely unexpected evidence of earlier earth movements, probably in 1868, which also affected a large area.

The purpose of this paper is to set forth fully the amount and nature of these two great displacements of large portions (at least 4,000 square miles) of the earth's crust and to indicate the degree of certainty in regard to these displacements warranted by the evidence.

EXTENT OF NEW TRIANGULATION.

The new triangulation done during the interval July 12, 1906, to July 2, 1907, extends continuously northwestward from Mount Toro, in Monterey County, and Santa Ana Mountain, in San Benito County, to Ross Mountain, and the vicinity of Fort Ross, in Sonoma County. This new continuous triangulation, as indicated on map No. 24, extends over an area 270 kilometers (170 miles) long and 80 kilometers (50 miles) wide, at its widest part. It includes the station known as Mocho, about $11\frac{1}{2}$ miles northeast from Mount Hamilton

[1] Published by permission of the Superintendent of the Coast and Geodetic Survey.
[2] See Appendix 9 of the Report of the Coast and Geodetic Survey for 1904, Triangulation in California, Part I, by A. L. Baldwin, Computer.
[3] Preliminary Report, State Earthquake Investigation Commission, Berkeley, May 31, 1906.

and a station on Mount Diablo, both on the eastern side of the fault and 53 kilometers (33 miles) from it. It also includes the Farallon Light-house on the west side of the fault and 36 kilometers (22 miles) from it. There were, in all, 51 old triangulation stations which were recovered and their new positions accurately determined by the new triangulation. The stations had been marked upon the ground by stone monuments, by bolts in rock, etc., or by permanent structures such as the Farallon Light-house, Point Reyes Light-house, and the small dome of Lick Observatory, or were themselves permanent marks; as, for example, Montara Mountain peak (a sharp peak).

This continuous scheme consists of a chain of primary triangulation comprizing the eleven occupied stations, Mount Toro, Gavilan, Santa Cruz Azimuth Station, Loma Prieta, Sierra Morena, Mocho, Mount Tamalpais, Point Reyes Hill, Tomales Bay, Sonoma Mountain, and Ross Mountain; triangulation of the secondary grade of accuracy extending from the stations, Mount Tamalpais, Mount Diablo, Rocky Mound, and Red Hill, to the Pulgas Base near the southern end of San Francisco Bay, and triangulation of a tertiary grade of accuracy in three different localities; namely, in the vicinity of Colma, west of San Francisco Bay, along Tomales Bay, and in the vicinity of Fort Ross, Sonoma County.

The primary and secondary triangulation are shown on map No. 24, and the tertiary triangulation on map No. 25. On these two maps the straight blue lines indicate lines over which observations were taken in the new triangulation. The small red circles indicate stations marked upon the ground, of which the relative positions were fixt by the triangulation. Observations were taken in both directions over each blue line which is unbroken, thruout its length. Observations were taken in one direction, only, from the solid end toward the broken end, over each blue line which is broken at one end. A station from which no blue line is drawn unbroken was not occupied. The position of such a station was determined by intersections from the occupied stations.

In addition to this continuous triangulation, a detached piece of new triangulation of the secondary grade of accuracy, connecting old triangulation stations, was done in the vicinity of Point Arena. (See map No. 25.) This makes the total number of old triangulation stations which were recovered and redetermined 61.

In connection with the new triangulation, astronomic determinations of azimuth or true direction were made by observations on Polaris at the stations Mount Tamalpais, Mocho, and Mount Toro.

Four different observers, each with his own complete outfit and party, were engaged in the new work for an aggregate period of 35 months. The observers were all field officers of the Coast and Geodetic Survey, with previous experience in triangulation.

Mr. J. F. Pratt, Assistant, was in the field from August 4, 1906, to July 2, 1907, and made the observations at the five primary stations, Ross Mountain, Sonoma Mountain, Tomales Bay, Point Reyes Hill, and Mount Tamalpais.

Mr. W. B. Fairfield, Assistant, was in the field from August 11, 1906, to May 29, 1907. He did nearly all of the Tomales Bay triangulation, made the observations at the primary stations, Mocho and Sierra Morena, and did a part of the secondary triangulation in the vicinity of Pulgas Base.

Mr. C. H. Sinclair, Assistant, was in the field from July 14, 1906, to April 10, 1907. He made the observations at the primary stations, Santa Cruz Azimuth Station, Loma Prieta, Gavilan, and Mount Toro, and also did a part of the secondary triangulation in the vicinity of Pulgas Base.

Mr. Edwin Smith, Assistant, was in the field from July 12 to July 24, 1906, engaged in making the reconnaissance and other preparations for triangulation along Tomales Bay. He was then called away on other duty and Assistant Fairfield completed the Tomales Bay triangulation. Between September 26, 1906, and February 26, 1907, Mr. Smith did

the secondary triangulation in the vicinity of Point Arena and the tertiary triangulation in the vicinity of Fort Ross and in the vicinity of Colma.

These observers remained at their work continuously in spite of many delays and discomforts due to fog, rain, snow, gales, and roads which were at times nearly or quite impassable. To them must be given the credit for overcoming the difficulties and securing the observations of the necessary high grade of accuracy.

THE OLD TRIANGULATION.

The old triangulation fixing the positions of the points before the earthquake of April 18, 1906, was done in many years, extending from 1851 to 1899, as a part of the regular work of the Coast and Geodetic Survey and without reference to the possible future use of this triangulation as a means of determining the movements of permanent character due to earthquakes. During the earlier years certain parts of this old triangulation had existed as detached triangulation not connected with other parts. Before 1906, however, all parts of the old triangulation had been connected with each other by triangulation to form one continuous scheme. It was also connected with other triangulation extending to many parts of the United States, including many of the interior states, as well as the Atlantic and Gulf Coasts.

In connection with studies of the evidence as to the earth movements set forth in this paper, it is important to note briefly the dates of the old triangulation which serves, in connection with the new triangulation of 1906–1907, to determine changes in positions of marked points on the earth's surface.

During the years 1854–1860 primary triangulation was carried from the stations, Rocky Mound, Red Hill, and Mount Tamalpais, northward to Ross Mountain, thru a primary scheme practically identical with that shown on map No. 24, except that the station Bodega was occupied in this earlier triangulation, tho not in 1906–1907.

Tertiary triangulation, following substantially the scheme shown on map No. 25, was also done in 1856 to 1860, along Tomales Bay, starting with the line Tomales Bay-Bodega, of the primary triangulation referred to in the preceding paragraph. In connection with this work, the station Chaparral of the Fort Ross triangulation, shown on map No. 25, was also determined.

Primary triangulation was done during the years 1851 to 1854, connecting the group of stations, Mount Diablo, Rocky Mound, Red Hill, with the Pulgas Base, the scheme being somewhat different from that shown on map No. 24, but equally direct and strong.

During the years 1854–1855, 1864, 1866, primary triangulation was done connecting the stations in the vicinity of Rocky Mound, referred to in the preceding paragraph, with stations Gavilan, Santa Cruz, and Point Pinos Light-house around Monterey Bay. This triangulation, for the greater part of its length, consists of a single chain of triangles, affording, therefore, comparatively few checks upon the results.

This practically completes the statement of triangulation done before 1868 which is concerned in the present investigation. The extent of the triangulation done between 1868 and 1906 is stated separately in the following paragraphs.

Northward of the line Mount Diablo-Mount Tamalpais, but one station of the primary scheme, shown on map No. 24, was determined by primary triangulation in the interval 1868–1906; namely, Ross Mountain. It was determined directly from the stations Mount Tamalpais, Mount Diablo, and Mount Helena of the transcontinental triangulation.[1]

During the years 1876–1887, primary triangulation was extended southward (by substantially the same scheme as that shown on map No. 24, except that station Gavilan was omitted) from the line Mount Diablo-Mount Tamalpais to the line Mount Toro-

[1] See The Transcontinental Triangulation, Special Publication No. 4, pp. 597–608.

Santa Ana. Some pointings were also taken on Gavilan, Point Pinos Light-house, and other stations in this vicinity, but not from a sufficient number of stations to furnish checked determinations independent of earlier determinations made before 1868.

Secondary triangulation near Point Arena, forming the western extremity of the transcontinental triangulation, was done in the interval 1870–1892, the scheme being substantially the same as that shown on map No. 25, except that all stations were occupied. The triangulation fixing the initial stations, Fisher and Cold Spring, has been published.[1]

Tertiary triangulation in the vicinity of Fort Ross was done in 1875-1876, following a scheme similar to that shown on map No. 25, and starting from the line Bodega Head-Ross Mountain, as determined before 1868.

Tertiary triangulation was done during various years from 1851–1899, extending from the vicinity of the Pulgas Base northward, spanning San Francisco Bay, to the Golden Gate, and thence southward to the vicinity of Colma, including stations shown on sketch No. 4 on map No. 25. The greater portion of this triangulation was done before 1868, but it is impracticable to separate the computations into two parts dealing with triangulation before and triangulation after 1868, respectively.

PERMANENT DISPLACEMENTS PRODUCED BY THE EARTHQUAKES OF 1868 AND 1906.

The following tables, Nos. 1, 2, and 3, show the permanent displacements of various points as caused by the earthquakes of 1868 and 1906. These permanent displacements were determined by comparisons of the positions of identical points upon the earth's surface as determined by triangulation done before and after the earthquakes in question.

While for the sake of brevity in statement these movements are referred to the earthquakes of 1868 and 1906, the evidence furnished by the triangulation simply indicates the fact that the displacements in question took place sometime during the two blank intervals within which there was no triangulation done fixing the points in question; namely, the interval 1866–1874, including the 1868 earthquake, and the interval 1892 to July, 1906, including the 1906 earthquake. Neither does the triangulation furnish any evidence indicating whether the displacements took place gradually, extending over many months and possibly years, or whether they took place suddenly. The evidence connecting the displacements of 1906 with the particular earthquake and indicating that they were sudden comes from other sources and will be commented upon later in this report.

The permanent displacements indicated in tables 1, 2, and 3, must be carefully distinguished from the vibrations of a more or less elastic character which take place during earthquakes. These vibrations die down in a few seconds, minutes, or hours. While they are in progress, a given point on the earth's surface is in continuous motion along a more or less complicated path which turns upon itself and leaves the point, at the end of the vibration, near the initial position. The displacements indicated in tables 1, 2, and 3, on the other hand, remain for years, possibly for centuries. They are of a permanent character. The displaced point remains in the new position until another displacement occurs in some later earthquake, or possibly by slow relief of strain accompanied by a creeping motion which causes a new permanent displacement. In tables 1, 2, and 3, the first column gives the name of the station by which it may also be identified on map 24 or on map 25, or both. The second column gives its latitude at the time indicated in the heading. The third column gives the seconds, only, of the new latitude at the later time indicated in the heading. The fourth and fifth columns have the same significance with reference to the longitude that the second and third have with reference to the latitude of each point. The sixth column gives the north and south component of the displace-

[1] See The Transcontinental Triangulation, Special Publication No. 4, pp. 597–610.

Table 1.—Displacements of 1906.

STATION	LATITUDE AFTER 1868	LATITUDE 1906–07	LONGITUDE AFTER 1868	LONGITUDE 1906–07	SOUTHWARD COMPONENT OF DISPLACEMENT	EASTWARD COMPONENT OF DISPLACEMENT	DIRECTION OF DISPLACEMENT	AMOUNT OF DISPLACEMENT		RELATION TO FAULT			DEGREE OF CERTAINTY
					Meters	Meters		Meters	Feet	Km.	Miles	Dir.	
GROUP 1.													
Rocky Mound	37° 52′ 57.253″	57.262″	122° 14′ 30.507″	30.515″	− 0.28	− 0.20	145°	0.34	1.1	32	20	E	Doubtful.
Red Hill	37 33 04.730	04.738	122 05 40.982	40.975	− 0.25	+ 0.17	215	0.30	1.0	19	12	E	Do.
Sierra Morena	37 24 38.266	38.305	122 18 28.006	28.054	− 1.20	− 1.18	136	1.68	5.5	4.3	2.7	W	Certain.
Mount Tamalpais	37 55 27.507	27.492	122 35 45.242	45.228	+ 0.46	+ 0.34	324	0.58	1.9	6.4	4.0	E	Do.
Farallon Lighthouse	37 41 58.250	58.277	123 00 03.605	03.669	− 0.83	− 1.57	118	1.78	5.8	37	23	W	Do.
Pt. Reyes Light-house	37 59 45.458	45.572	123 01 20.577	20.618	− 0.43	− 1.00	113	1.09	3.6	19	12	W	Doubtful.
Point Reyes Hill	38 04 48	......	122 52 01	......	(− 2.96)	(− 2.25)	(143)	(3.72)	(12.2)	2.7	1.7	W	Inferred, certain.
Tomales Bay	38 10 55	......	122 56 47	......	(− 3.06)	(− 2.41)	(142)	(3.89)	(12.8)	2.1	1.3	W	Do.
Bodega	38 18 24	......	123 00 04	......	(+ 1.16)	(+ 0.89)	(323)	(1.47)	(4.8)	2.0	1.2	E	Inferred, reasonably certain.
Ross Mountain	38 30 20.583	20.572	123 07 09.221	09.204	+ 0.34	+ 0.41	309	0.53	1.8	7.0	4.3	E	Doubtful.
GROUP 3.													
Black Ridge 2	37 44 54.214	54.207	122 27 59.502	59.505	+ 0.22	− 0.07	19	0.23	0.7	7.0	4.3	E	Doubtful.[1]
Bonita Pt. Light-house	37 48 57.447	57.363	122 31 43.569	43.554	+ 2.59	+ 0.37	352	2.62	8.6	6.0	3.7	E	Do.
San Bruno Mountain	37 41 16.130	16.129	122 26 05.344	05.334	+ 0.03	+ 0.24	277	0.25	0.8	5.1	3.2	E	Do.
Black Bluff	37 43 10.158	10.149	122 30 12.684	12.672	+ 0.28	+ 0.29	313	0.40	1.3	2.5	1.6	E	Do.
Road	37 37 57.595	57.665	122 28 28.512	28.559	− 2.16	− 1.15	152	2.45	8.0	1.5	0.9	W	Do.
Flat	37 36 51.991	52.060	122 27 35.197	35.236	− 2.13	− 0.96	156	2.33	7.7	1.5	0.9	W	Do.
False Cattle Hill 2	37 36 50.401	50.460	122 29 40.926	40.967	− 1.82	− 1.01	151	2.08	6.8	4.1	2.5	W	Do.
Montara Mountain Pk.	37 33 42.506	42.549	122 28 36.940	36.904	− 1.33	+ 0.88	214	1.59	5.2	6.1	3.8	W	Do.
San Pedro Rock	37 35 44.158	44.239	122 31 22.422	22.441	− 2.50	− 0.47	169	2.54	8.3	7.4	4.6	W	Do.
GROUP 4.													
Bodega Head	38 18 29	......	123 03 45	......	(− 3.56)	(− 0.52)	(172)	(3.60)	(11.8)	2.2	1.4	W	Inferred, certain.
Tomales Point	38 12 46	......	122 58 14	......	(− 2.81)	(− 2.24)	(141)	(3.59)	(11.8)	2.0	1.2	W	Do.
Foster	38 08 13	......	122 54 23	......	(− 3.61)	(− 2.83)	(142)	(4.59)	(15.1)	1.9	1.2	W	Do.
Smith	38 14 52	......	122 56 09	......	(+ 1.46)	(+ 0.80)	(331)	(1.66)	(5.4)	2.6	1.6	E	Do.
Mershon	38 10 55	......	122 54 06	......	(+ 1.90)	(+ 0.42)	(348)	(1.95)	(6.4)	1.1	0.7	E	Do.
Hans	38 07 58	......	122 52 02	......	(+ 1.94)	(− 0.23)	(7)	(1.95)	(6.4)	0.5	0.3	E	Inferred, doubtful.
Hammond	38 04 45	......	122 48 35	......	(+ 1.79)	(− 1.42)	(38)	(2.28)	(7.5)	1.2	0.7	E	Do.

GROUP 5.																	
Peaked Hill	38	25	53.725	53.704	123	07	04.450	04.405	+ 0.65	+ 1.09	301	1.27	4.2	2.0	1.2	E	Reasonably certain.
Lancaster	38	37	16.134	16.086	123	18	44.268	44.228	+ 1.48	+ 0.97	327	1.77	5.8	2.0	1.2	E	Do.
Chaparral	38	29	33.964	33.927	123	10	56.216	56.187	+ 1.14	+ 0.70	328	1.34	4.4	1.8	1.1	E	Do.
Dixon	38	30	30.735	30.703	123	11	54.496	54.457	+ 0.99	+ 0.94	316	1.37	4.5	1.8	1.1	E	Do.
Henry Hill	38	32	47.724	47.688	123	14	27.513	27.474	+ 1.11	+ 0.94	320	1.46	4.8	1.5	0.9	E	Do.
Salt Point	38	34	00.302	00.350	123	19	57.771	57.827	− 1.48	− 1.36	138	2.01	6.6	3.2	2.0	W	Do.
Horseshoe Point . .	38	36	27.969	28.004	123	22	09.462	09.504	− 1.08	− 1.02	137	1.48	4.9	2.9	1.8	W	Do.
Stockhoff	38	32	56.969	57.016	123	18	11.870	11.913	− 1.45	− 1.04	144	1.78	5.9	2.6	1.6	W	Certain.
Timber Cove . . .	38	31	59.557	59.615	123	16	35.519	35.573	− 1.79	− 1.31	144	2.22	7.3	1.9	1.2	W	Do.
Fort Ross	38	30	46.084	46.152	123	15	12.655	12.711	− 2.10	− 1.36	147	2.50	8.2	1.9	1.2	W	Do.
Pinnacle Rock . . .	38	30	02.982	03.056	123	14	02.956	02.995	− 2.28	− 0.94	158	2.47	8.1	1.6	1.0	W	Do.
Funcke	38	34	34.972	35.029	123	18	07.323	07.386	− 1.76	− 1.52	139	2.33	7.6	0.4	0.2	W	Do.
GROUP 6.																	
Cold Spring	39	01	21.370	......	123	31	20.468	......	......	......	....	....	....	13.5	8.4	E	Assumed unmoved.
Fisher	39	03	59.721	......	123	35	11.758	......	......	......	....	....	....	11.2	7.0	E	Do.
Dunn	39	00	39.986	39.964	123	38	40.716	40.699	+ 0.68	+ 0.41	329	0.79	2.6	3.9	2.4	E	Certain.
Clark	38	59	37.744	37.721	123	37	53.842	53.824	+ 0.71	+ 0.43	329	0.83	2.7	3.8	2.4	E	Do.
Spur	38	59	16.549	16.509	123	40	13.994	13.957	+ 1.23	+ 0.89	324	1.52	5.0	0.5	0.3	E	Do.
Lane	39	00	34.636	34.590	123	41	35.602	35.580	+ 1.42	+ 0.53	340	1.51	5.0	0.2	0.1	E	Do.
Shoemake	38	57	58.425	58.527	123	40	57.846	57.883	− 3.14	− 0.89	164	3.27	10.7	1.5	0.9	W	Do.
Point Arena Cath. Ch.	38	54	45.079	45.162	123	41	36.283	36.315	− 2.56	− 0.77	163	2.67	8.8	5.7	3.5	W	Do.
Pt. Arena Light-house	38	57	18.722	18.797	123	44	23.887	23.920	− 2.31	− 0.80	161	2.45	8.0	6.4	4.0	W	Do.
Sinclair	38	54	39.582	39.661	123	42	19.095	19.129	− 2.44	− 0.82	161	2.57	8.4	6.7	4.2	W	Do.
High Bluff	38	54	03.866	03.950	123	41	53.305	53.347	− 2.59	− 1.01	159	2.78	9.1	6.8	4.2	W	Do.
Arena	38	55	18.927	19.005	123	43	36.908	36.942	− 2.40	− 0.82	161	2.54	8.3	7.6	4.7	W	Do.
GROUP 7.																	
Lick Obs., small dome	37	20	31.511	31.511	121	38	31.707	31.702	0.00	+ 0.12	270	0.12	0.4	36	22	E	Doubtful.
Loma Prieta . . .	37	06	40.912	40.895	121	50	36.423	36.390	+ 0.52	+ 0.82	303	0.97	3.2	4.8	3.0	E	Certain.
Santa Cruz Light-house	36	57	08.821	08.837	122	01	33.667	33.682	− 0.49	− 0.37	143	0.62	2.0	19	12	W	Doubtful.
Mount Toro	36	31	34.712	34.742	121	36	32.276	32.284	− 0.92	− 0.20	168	0.95	3.1	32	20	W	Uncertain.
Santa Cruz Az. Sta. .	36	58	42	......	122	03	19	......	(+ 0.61)	(− 1.78)	(71)	(1.88)	(6.2)	19	12	W	Inferred, very doubtful.
Gavilan	36	45	21	......	121	31	11	......	(+ 1.48)	(+ 1.62)	(312)	(2.19)	(7.2)	6.4	4.0	W	Do.
Pt. Pinos Light-house	36	38	01	......	121	55	59	......	(+ 2.86)	(+ 1.16)	(338)	(3.09)	(10.1)	39	24	W	Do.
Point Pinos Lat. Sta. .	36	37	59	......	121	55	32	......	(+ 2.31)	(+ 0.24)	(354)	(2.32)	(7.6)	39	24	W	Do.

[1] Though the absolute displacements in Group 3 are all doubtful, only two of the relative displacements are doubtful; namely, Bonita Point Light-house and Montara Mountain Peak.

Table 2.—Permanent Displacements in 1868.

STATION	Latitude before 1868	Latitude after 1868	Longitude before 1868	Longitude after 1868	Southward Component of Displacement	Eastward Component of Displacement	Direction of Displacement	Amount of Displacement		Degree of Certainty
					Meters	Meters		Meters	Feet	
Group 1.										
Rocky Mound . . .	37° 52′ 57.237″	57.253″	122° 14′ 30.510″	30.507″	− 0.49	+ 0.07	188°	0.50	1.6	Doubtful.
Red Hill	37 33 04.717	04.730	122 05 41.003	40.982	− 0.40	+ 0.52	232	0.65	2.1	Do.
Mount Tamalpais . .	37 55 27.455	27.507	122 35 45.228	45.242	− 1.60	− 0.34	168	1.64	5.4	Certain.
Farallon Light-house .	37 41 58.210	58.250	123 00 03.579	03.605	− 1.23	− 0.64	153	1.39	4.6	Do.
Point Reyes Hill . .	38 04 48.325	......	122 52 00.801	......	(− 1.51)	(− 0.31)	(168)	(1.54)	(5.0)	Inferred, certain.
Tomales Bay . . .	38 10 55.456	......	122 56 46.733	......	(− 1.56)	(− 0.22)	(172)	(1.57)	(5.2)	Do.
Bodega	38 18 23.680	......	123 00 03.726	......	(− 1.62)	(− 0.11)	(176)	(1.62)	(5.3)	Inferred, reasonably certain.
Ross Mountain . . .	38 30 20.528	20.583	123 07 09.223	09.221	− 1.70	+ 0.05	182	1.70	5.6	Reasonably certain.
Group 4.										
Bodega Head . . .	38 18 29.249	......	123 03 45.417	......	(− 1.62)	(− 0.11)	(176)	(1.62)	(5.3)	Inferred, certain.
Tomales Point . . .	38 12 45.732	......	122 58 14.449	......	(− 1.57)	(− 0.19)	(173)	(1.58)	(5.2)	Do.
Foster	38 08 13.410	......	122 54 23.271	......	(− 1.54)	(− 0.26)	(170)	(1.56)	(5.1)	Do.
Smith	38 14 51.518	......	122 56 08.865	......	(− 1.58)	(− 0.17)	(174)	(1.59)	(5.2)	Do.
Mershon	38 10 55.295	......	122 54 06.016	......	(− 1.56)	(− 0.22)	(172)	(1.57)	(5.2)	Do.
Hans	38 07 58.492	......	122 52 02.072	......	(− 1.54)	(− 0.28)	(170)	(1.57)	(5.2)	Inferred, doubtful.
Hammond	38 04 45.046	......	122 48 34.993	......	(− 1.51)	(− 0.31)	(168)	(1.54)	(5.1)	Do.
Group 5.										
Chaparral	38 29 33.905	33.964	123 10 56.207	56.216	− 1.82	− 0.22	173	1.83	6.0	Reasonably certain.
Group 7.										
Loma Prieta . . .	37 06 40.971	40.912	121 50 36.521	36.423	+ 1.82	+ 2.42	307	3.03	9.9	Certain.

Table 3.—Combined Displacements of 1868 and 1906.

STATION	Latitude before 1868	Latitude 1906-07	Longitude before 1868	Longitude 1906-07	Southward Component of Displacement	Eastward Component of Displacement	Direction of Displacement	Amount of Displacement		Relation to Fault			Degree of Certainty
					Meters	Meters		Meters	Feet	Km.	Miles	Dir.	
Group 1.													
Rocky Mound	37° 52′ 57.237″	57.262″	122° 14′ 30.510″	30.515″	− 0.77	− 0.12	171°	0.78	2.6	32	20	E	Doubtful.
Red Hill	37 33 04.717	04.738	122 05 41.003	40.975	− 0.65	+ 0.69	227	0.94	3.1	19	12	E	Certain.
Mount Tamalpais	37 55 27.455	27.492	122 35 45.228	45.228	− 1.14	0.00	180	1.14	3.7	6.4	4.0	E	Do.
Farallon Light-house	37 41 58.210	58.277	123 00 03.579	03.669	− 2.07	− 2.20	133	3.02	9.9	37	23	W	Do.
Point Reyes Hill	38 04 48.325	48.470	122 52 00.801	00.906	− 4.47	− 2.56	150	5.15	16.9	2.7	1.7	W	Do.
Tomales Bay	38 10 55.456	55.606	122 56 46.733	46.841	− 4.62	− 2.63	150	5.32	17.5	2.1	1.3	W	Do.
Bodega	38 18 23.680	23.695	123 00 03.726	03.694	− 0.46	+ 0.78	239	0.90	3.0	2.0	1.2	E	Reasonably certain.
Ross Mountain	38 30 20.528	20.572	123 07 09.223	09.204	− 1.36	+ 0.46	199	1.43	4.7	7.0	4.3	E	Do.
Sonoma Mountain	38 19 24.539	24.579	122 34 27.894	27.891	− 1.23	+ 0.07	183	1.24	4.0	34	21	E	Certain.
Group 2.													
Pulgas E. Base	37 28 36.265	36.258	122 08 08.143	08.129	+ 0.22	+ 0.34	302	0.41	1.3	12	7	E	Doubtful.
Guano Island	37 34 23.655	23.649	122 15 43.475	43.479	+ 0.18	− 0.10	28	0.21	0.7	10	6	E	Do.
Pulgas W. Base	37 28 48.787	48.764	122 15 15.681	15.673	+ 0.71	+ 0.20	344	0.74	2.4	3.5	2.2	E	Reasonably certain.
Group 4.													
Bodega Head	38 18 29.249	29.417	123 03 45.417	45.443	− 5.18	− 0.63	173	5.22	17.1	2.2	1.4	W	Certain.
Tomales Point	38 12 45.732	45.874	122 58 14.449	14.549	− 4.38	− 2.43	151	5.01	16.4	2.0	1.2	W	Do.
Foster	38 08 13.410	13.577	122 54 23.271	23.398	− 5.15	− 3.09	149	6.01	19.7	1.9	1.2	W	Do.
Smith	38 14 51.518	51.522	122 56 08.865	08.839	− 0.12	+ 0.63	259	0.64	2.1	2.6	1.6	E	Do.
Mershon	38 10 55.295	55.284	122 54 06.016	06.008	+ 0.34	+ 0.20	330	0.39	1.3	1.1	0.7	E	Do.
Hans	38 07 58.492	58.479	122 52 02.072	02.093	+ 0.40	− 0.51	52	0.65	2.1	0.5	0.3	E	Doubtful.
Hammond	38 04 45.046	45.037	122 48 34.993	35.064	+ 0.28	− 1.73	81	1.75	5.7	1.2	0.7	E	Do.
Group 5.													
Chaparral	38 29 33.905	33.927	123 10 56.207	56.187	− 0.68	+ 0.48	216	0.83	2.7	1.6	1.0	E	Doubtful.
Group 7.													
Black Mountain	37 19 09.810	09.761	122 08 49.462	49.402	+ 1.51	+ 1.48	316	2.11	6.9	1.4	0.9	E	Certain.
Loma Prieta	37 06 40.971	40.895	121 50 36.521	36.390	+ 2.34	+ 3.23	306	3.99	13.1	4.8	3.0	E	Do.
Santa Cruz Az. Sta.	36 58 42.106	42.027	122 03 18.728	18.702	+ 2.44	+ 0.64	345	2.52	8.3	19	12	W	Do.
Gavilan	36 45 21.068	20.961	121 31 11.504	11.341	+ 3.30	+ 4.04	309	5.22	17.1	6.4	4.0	W	Do.
Pt. Pinos Light-house	36 38 01.551	01.399	121 55 58.939	58.795	+ 4.68	+ 3.58	323	5.89	19.3	39	24	W	Do.
Point Pinos Lat. Sta.	36 37 59.413	59.279	121 55 31.685	31.578	+ 4.13	+ 2.66	327	4.91	16.1	39	24	W	Do.

ment along a meridian. A plus sign in this column means that the point moved toward the south. The seventh column shows the east and west component of the motion. A plus sign in this column means that the point moved toward the east. The sixth and seventh columns were computed by converting the changes in latitude and longitude, respectively, into meters.

By combining the values given in columns 6 and 7, the direction and amount of the displacement were obtained as shown in columns 8, 9, and 10. In column 8 the direction of displacement is given, reckoned as geodetic azimuths are usually reckoned, clockwise around the whole circumference from south as zero. In this reckoning, west is 90°, north, 180°, and east, 270°. Column 9 gives the amount of displacement in meters and column 10 gives it in feet. Column 11 shows the approximate distance of the point from the fault of 1906, measured approximately at right angles to the fault. In this column E indicates that the point is to the east of the fault and W that it is to the west.

For example: The fifth line of table 1 indicates that during the earthquake of 1906 the Farallon Light-house moved 0.83 meter north and 1.57 meters west, or, in other words, moved 1.78 meters (5.8 feet) in azimuth 118°, or 62° west of north, and that it is 37 kilometers (23 miles) from the fault of 1906 and to the west of it.

In the heading, the expression "Before 1868" refers to years within the interval 1851–1866. The expression "After 1868" refers to years within the interval 1874–1891, and "1906–1907" refers to dates within the interval July, 1906–July, 1907.

The latitudes and longitudes given in tables are all computed upon the U. S. Standard Datum and differ somewhat from those now in use on the charts and maps of this region. They are, however, the latitudes and longitudes to which all charts and maps should ultimately conform.

Table 1 shows the displacements which occurred on April 18, 1906; table 2 shows the displacements which occurred in 1868, and table 3 shows the total, or combined displacements in both 1868 and 1906.

For some cases, as, for example, Point Reyes Hill, the separate displacements were not directly determined by the triangulation but only the combined displacements. In such cases, if probable values could be derived for the separate displacements, indirectly, by inference from surrounding points, they were so derived and placed in the table. In each case, such inferred displacements are clearly distinguished in the table from others which were determined directly by measurement, by leaving the third and fifth columns blank and by having the values in the sixth to tenth columns enclosed in parentheses.

All of the displacements given in tables 1–3 are computed upon the assumption that the two stations, Mount Diablo and Mocho, remained unmoved during the earthquake of April 18, 1906. The reasons why this assumption is believed to be true will be set forth fully in a later part of this report.

In the tables the points are separated into seven groups for convenience of discussion. Each group of points is fixt by a portion of the triangulation which may conveniently be considered as a unit in discussing the magnitude of the possible errors of the triangulation. The discussion of the observed displacements and the degree of certainty in regard to them is given after the tables and deals with each group in succession.

The apparent displacements, as shown in the above tables, are of course in part due to the unavoidable errors in the triangulation and in part are doubtless actual displacements of the points. The triangulation furnishes within itself the means of estimating its accuracy. If the observations were absolutely exact, the sum of the observed angles of each triangle would be exactly 180° plus the spherical excess of that triangle, and moreover the computation of the length of the triangle sides would show no discrepancies, starting from a given line and ending on a selected line, but proceeding thru the various alternative sets of triangles which it is possible to select connecting said lines. In any

actual case, neither of these ideal conditions is found. Each triangle has a closing error, and the lengths computed along different paths thru the triangulation show discrepancies. These closing errors and discrepancies are a measure of the accuracy of the triangulation.

The triangulation, both old and new, was adjusted by the method of least squares. This method of computation, as applied to triangulation, takes into account simultaneously all the observed facts in connection with a group of triangulation stations and also all the known theoretical conditions connecting the observed facts; such, for example, as those mentioned in the preceding paragraph, in regard to closures of triangles and discrepancies in length. It is the most perfect method of computation known. The results of the computation are a set of lengths and azimuths (true directions) of lines joining the triangulation stations and of latitudes and longitudes defining the relative positions of the stations which are perfectly consistent; that is, contain no contradictions one with another and are the most probable values which can be derived from the observations. In such a computation, the measures of the accuracy of the computed results appear in the form of corrections to observed directions from station to station, which it is necessary to apply in order to obtain the most probable results given by the computation. The greater the accuracy of the observations the smaller are the corrections to directions.

In the problem in hand, in which, at least for some points, the observed apparent displacement is of about the same magnitude as the possible error in the apparent displacement due to accumulated errors of observation, it is necessary to make a careful estimate of the errors of observation and of the uncertainties of the computed displacements. This has been done and the estimates are given in general terms in the following text and are indicated in the last column of the tables. These estimates will help the reader to avoid drawing conclusions in detail not warranted by the facts.

Group 1. *Northern part of primary triangulation.*—In this group, as shown by tables 1–3 (see also map 24), there are 11 points of which the positions were redetermined after the earthquake of April 18, 1906. Of these, 9 had been determined before 1868 and 7 between 1868 and 1906.

There is about 1 chance in 3 that each of the two apparent displacements of Rocky Mound, 0.50 meter (1.6 feet), in 1868 (table 2), and 0.34 meter (1.1 feet), in 1906 (table 1), is simply the result of errors of observation. Similarly there is about 1 chance in 3 that the apparent displacement of Red Hill in 1868, 0.65 meter (2.1 feet), is the result of errors of observation. The chances are about even for and against the apparent displacement of Red Hill in 1906, 0.30 meter (1.0 foot), being simply the result of errors of observation. The effect of errors of observation upon the apparent displacements are larger at these two points than they otherwise would be on account of the difficulty in this vicinity of separating the triangulation into two complete schemes, one before 1868 and one after that date, each strong and complete.

According to the evidence furnished by the triangulation, the apparent displacement of Ross Mountain in 1906, 0.53 meter (1.8 feet) in azimuth 309° (51° E. of S.), is probably the result of errors of observation. This apparent displacement as computed depends on the accumulated errors of the two triangulations from Mount Diablo to Ross Mountain, a distance of 130 kilometers (81 miles). The apparent displacement of 0.53 meter almost directly toward Mount Diablo corresponds to a shortening on the line Ross Mountain-Mount Diablo by 1 part in 250,000, too small a change to be detected with certainty by the triangulation.

On the other hand, there is about 1 chance in 15 that the apparent displacement of Ross Mountain in 1868, 1.70 meters (5.6 feet), is due to errors of observation. It is reasonably certain that this is a real displacement.

The chances are about even for and against the apparent displacement of Point Reyes Light-house in 1906, 1.09 meters (3.6 feet), being due simply to errors of observation.

There is about 1 chance in 7 that the apparent displacement of Bodega, shown in table 3, is due to errors of observation. It is reasonably certain that this is a real displacement.

For the remaining six points in group 1, Sierra Morena, Mount Tamalpais, Farallon Light-house, Point Reyes Hill, Tomales Bay, and Sonoma Mountain, each of the apparent displacements given in the tables as observed is real, being in each case clearly beyond the maximum which could be accounted for as errors of observation.

Prof. George Davidson has believed for many years that Mount Tamalpais moved during the earthquake of 1868 and that the triangulations made before and after that date showed such a displacement. Accordingly in 1905, at his request, a reëxamination was made at the Coast and Geodetic Survey office of the evidence furnished by the triangulations, and the conclusion was reached that a real displacement of Mount Tamalpais occurred in 1868. At that time, however, convincing evidence was not discovered that any other triangulation station moved in 1868. In the more extensive studies made in connection with the present investigation, and with the additional skill acquired in recognizing the effects of earthquakes upon triangulation, it became evident, as shown in table 2, not only that Mount Tamalpais moved in 1868, but also that the Farallon Light-house and Ross Mountain moved at that time, the three apparent displacements being clearly beyond the range of possible errors of triangulation. The displacements for these three stations are similar. The amount of the displacement is least at Farallon Light-house, 1.39 meters (4.6 feet), and greatest at Ross Mountain, 1.70 meters (5.6 feet). The azimuth of the displacement is least at the Farallon Light-house, 153° (27° W. of N.), and is greatest at Ross Mountain, 182° (2° E. of N.). (See map 24.) The apparent differences in direction and amount of the three displacements may or may not be real. It is certain therefore that in 1868 the large part of the earth's surface included between these three stations, at least 700 square miles, moved about 1.5 meters (4.9 feet), in about azimuth 168° (12° W. of N.).

Within the triangle defined by the three stations, Mount Tamalpais, Farallon Light-house, and Ross Mountain, which certainly were displaced in 1868, are the three stations, Point Reyes Hill, Tomales Bay, and Bodega, of group 1. It is therefore believed to be reasonably certain that these stations were displaced at that time. The probable displacements were interpolated from the three displacements observed at the first three stations, taking into account the relative positions of the stations. The resulting interpolated displacements are shown in table 2. Other evidence, tending to show that these interpolated values of the displacements are real, will be brought forward later.

For the three stations, Point Reyes Hill, Tomales Bay, and Bodega, the positions were determined before 1868 and after the earthquake of 1906, but not during the interval 1868–1906; hence the computation of the positions determined by triangulation for these stations furnishes simply the combined displacements of 1868 and 1906 as shown in table 3. As noted in the preceding paragraph, the displacement of 1868 has, for these three stations, been interpolated from surrounding stations and entered in table 2. The differences[1] between these inferred displacements in table 2 and the observed combined displacements in table 3 were then taken and are shown in table 1, as inferred displacements in 1906. As indicated in the marked column of table 1, these inferred displacements are believed to be certain for two of these points and somewhat doubtful for the third, Bodega.

The doubtful apparent displacements at Rocky Mound and Red Hill in 1868 (see table 2) agree with other displacements which are certain, in having a decided northward component.

In table 1, showing the displacements of 1906, there are three stations, Sierra Morena, Mount Tamalpais, and Farallon Light-house, at which observed displacement is certain,

[1] The differences were taken separately for the meridian components and the prime vertical components and then combined to secure the direction and amount of the resultant.

and two others, Point Reyes Hill and Tomales Bay, in group 1, at which the displacement inferred from indirect evidence is considered certain. Of these five stations, the four which are to the westward of the fault of 1906 moved northwestward and the one which is to the eastward of the fault, Mount Tamalpais, moved southeastward (see map 24). The displacements of four of the five points were nearly parallel, their azimuths being for Sierra Morena, Point Reyes Hill, and Tomales Bay, 136°, 143°, and 142° respectively, with a mean of 140° (40° W. of N.), while that of Mount Tamalpais was 324° (36° E. of S.). The azimuth of the displacement at the fifth, Farallon Light-house, is 118° (62° W. of N.) at an angle of about 22° with the other four. The portion of the fault near these points has an azimuth of about 145° (35° W. of N.), hence the displacement of four of the five points was practically parallel to the fault, the departure being in each case within the range of possible error of the determination of the displacement. For the four points to the westward of the fault, the amounts of the displacement are in the inverse order of their distances from the fault, with the exception of Sierra Morena. For Tomales Bay, which is only 2.1 kilometers (1.3 miles) from the fault, the displacement is greatest, 3.89 meters (12.8 feet), and for the Farallon Light-house, which is 37 kilometers (23 miles) from the fault, the displacement is much less, 1.78 meters (5.8 feet).

From these five stations, one may deduce four laws governing the distribution of the earth movement which occurred on April 18, 1906. First, points on opposite sides of the fault moved in opposite directions, those to the eastward of the fault in a southerly direction and those to the westward in a northerly direction. Second, the displacements of all points were approximately parallel to the fault. Third, the displacements on each side of the fault were less, the greater the distance of the displaced points from the fault. Fourth, for points on opposite sides of the fault and the same distance from it, those on the western side were displaced on an average about twice as much as those on the eastern side.

If the proof of these four deduced laws rested upon the evidence of these five stations only, it would be insufficient to convince one. Much other evidence in proof of these four deduced laws will be shown in this report. The laws are here stated in order that they may be kept in mind and tested by the evidence as presented.

The apparent displacements of the remaining five points of group 1 may now be compared with the stated laws.

The displacement of Point Reyes Light-house, believed to be determined with reasonable certainty, is apparently about 1.6 meters (5 feet) greater than and differs about 32° in direction from the displacement which might be inferred from the above laws and comparison with the surrounding stations.

The displacement of Bodega, of which the determination is somewhat doubtful, is just what would be inferred from the deduced laws, as its amount is greater than for Mount Tamalpais, corresponding to the fact that it is closer to the fault, and its azimuth agrees within 2° with that of the fault.

The displacement of Ross Mountain, of which the determination is doubtful, agrees very closely in amount with that at Mount Tamalpais and differs only 15° in direction. Ross Mountain is on the same side of the fault as Mount Tamalpais and at practically the same distance from it.

The apparent displacements of Rocky Mound and Red Hill, 32 and 19 kilometers (20 and 12 miles) from the fault and to the eastward of it, of which the determinations are doubtful, agree with the laws in being small but are contradictory as to direction.

For Sonoma Mountain the triangulation serves to determine the combined displacements of 1868 and 1906 as shown in table 3, but not the separate displacements, as this station was not involved in triangulation done between 1868 and 1906. The combined displacements at Sonoma Mountain are of about the same amount and are in approximately the same azimuth as displacements of 1868 at Mount Tamalpais, Point Reyes Hill, Tomales

Bay, Bodega, and Ross Mountain (see table 2). Some of the internal evidence of computations of triangulation indicate that Sonoma Mountain moved in 1868. According to the general laws of distribution of the earth movement of 1906 as derived from other stations Sonoma Mountain did not move much, if any, being far to the eastward of the fault, 34 kilometers (21 miles). For these three reasons it is believed to be probable that the whole displacement of Sonoma Mountain, 1.24 meters (4.0 feet), in azimuth 183° (3° E. of N.), which certainly took place sometime between 1860 and July, 1906, all occurred in 1868.

Group 2. *Southern end of San Francisco Bay.* — In this group there are three new points not yet considered and Red Hill which has already been considered in group 1. The three new stations, Guano Island, Pulgas East Base, and Pulgas West Base (see map 24), were determined in 1851–1854 and again after the earthquake of 1906. No determination was made between 1868 and 1906, hence these points are entered in table 3, the combined displacements of 1868 and 1906 being determined, but not the separate displacements.

A study of the errors of the triangulation shows that the apparent displacement of Guano Island, 0.21 meter (0.7 foot), is probably due to errors of observation, and that there is one chance in three that the apparent displacement of Pulgas East Base, 0.41 meter (1.3 feet), is also due to errors of observation.

The determination of the displacement of Pulgas West Base, 0.74 meter (2.4 feet), is reasonably certain, there being about one chance in twelve that it is due to errors of observation.

Tho the determinations of the separate apparent displacements of Red Hill in 1868, 0.65 meter (2.1 feet), and in 1906, 0.30 meter (1.0 foot), are each doubtful, the combined displacement as observed, shown in table 3, 0.94 meter (3.1 feet), is certain.

It is therefore reasonably certain that there was a relative displacement of Pulgas West Base and Red Hill as indicated in table 3, Red Hill moving 0.94 meter (3.1 feet), in azimuth 227° (47° E. of N.), and Pulgas West Base 0.74 meter (2.4 feet), in azimuth 344° (16° E. of S.). This lengthened the line Pulgas West Base to Red Hill, 16 kilometers (10 miles) long, 0.50 meter (1.6 feet), or one part in 32,000. It also changed the azimuth of this line by 11″, from 240° 44′ 35″ to 240° 44′ 24″, rotating it in a counterclockwise direction.

The red arrows on map 24, showing apparent displacements, indicate that the apparent displacements of Guano Island and Pulgas East Base, which are considered doubtful, are not inconsistent with the displacements of Red Hill and Pulgas West Base. Apparently the area included between these four stations was distorted by stretching and rotated in a counterclockwise direction.

There is no evident method of ascertaining whether the displacement of Pulgas West Base took place in 1868 or 1906 or in part at each time. The displacement is nearly in the direction corresponding to the laws governing the displacements of 1906, as already stated in connection with group 1. Pulgas West Base is to the eastward of the fault of 1906 and slightly nearer to it than Mount Tamalpais and Ross Mountain and hence, according to the laws referred to, should be displaced in the same direction as these two points (see table 1), and by a similar amount. This is the fact.

Group 3. *Vicinity of Colma.* — There are nine points in group 3 all determined by triangulation in 1899 or earlier, and redetermined after the earthquake of 1906 (see table 1). The earlier determination was made by secondary and tertiary triangulation, extending from the vicinity of Pulgas Base northwest, spanning San Francisco Bay to the Golden Gate, and thence southward to Colma. The earlier positions of these nine points are subject to the effect of accumulated errors in this chain of triangulation about 60

kilometers (40 miles) long. They are subject, therefore, to an error of position common to them all, which may be as great as 7 meters (23 feet). With the exception of Montara Mountain Peak and Bonita Point Light-house these points are all within 13 kilometers (8 miles) of San Bruno Mountain and therefore their relative positions were determined with considerable accuracy.

In the triangulation of 1906–1907, the position of San Bruno Mountain, which is in the midst of this group, was determined by secondary triangulation in connection with group 2 as indicated on maps 24 and 25, a direct and strong determination. The new azimuth was also carried into the triangulation of group 3 with a high degree of accuracy in this same manner. No new determination was made of the starting length in group 3. It was assumed that the length San Bruno Mountain to Black Ridge 2 had remained unchanged during the earthquake of 1906 and the old value of that length was used in the computation of the triangulation of 1906–1907. As a check upon the assumption that this length remained unchanged, it is to be noted that the azimuths of this line before and after the earthquake of 1906 were found to differ only by 9.3", which is within the possible range of errors of observation in the earlier triangulation.

For the reasons stated above, the apparent absolute displacements shown in table 1 for group 3, as referred to Mocho and Mount Diablo as fixt points, are probably due to errors of observation.

On account, however, of the fact that seven of the nine points in this group are within a rather small area, their relative displacements are determined with considerable accuracy, the errors of length and azimuth having less effect in producing errors in relative positions, the smaller the area covered by a triangulation. Montara Mountain Peak and Bonita Point Light-house are each determined with a low grade of accuracy. They are each far from the stations occupied in the triangulation and the lines which determine them intersect at a small angle; hence even their relative displacements are uncertain. The relative displacements observed for the remaining seven points after omitting these two are certain, being beyond the possible range of errors of observation.

The apparent absolute displacements for this group of points (see table 1 and map 25) indicate that all points on the eastern side of the fault moved in a southerly direction, and those on the western side in a northerly direction; that the displacements tend to be parallel to the fault, the more doubtful displacements showing the greater angles with the fault; and that the amounts of the displacement are in the inverse order of the distances of the stations from the fault, with two exceptions. These exceptions are San Pedro Rock, of which the relative displacement is determined with sufficient accuracy to establish this as a real exception; and Bonita Point Light-house, for which the apparent displacement as observed is so uncertain that this apparent exception has but little significance. Of the four points, all on the western side of the fault, of which the relative displacements are believed to be certain, as indicated in table 1, the azimuths of the displacements vary from 151° to 169°, with a mean of 157° (23° W. of N.). The azimuth of the fault in this vicinity is 144° (36° W. of N.).

The relative displacements on opposite sides of the fault and near to it are less in this group (2 to 3 meters) than for points at a similar distance from the fault in group 1; namely, Point Reyes Hill, Tomales Bay, and Bodega (5 to 6 meters).

Group 4. *Tomales Bay.* — There are seven points in this group (see tables 1 to 3 and maps 24 and 25). These were fixt in 1856–1860 by tertiary triangulation extending southeastward along Tomales Bay from stations Tomales Bay and Bodega of group 1. They were fixt again in practically the same manner in 1906 after the earthquake.

With these seven points may advantageously be considered the three points, Point Reyes Hill, Tomales Bay, and Bodega, which were fixt in group 1.

No one of these ten points was determined between 1868 and 1906, hence the observations served to determine the combined displacements of 1868 and 1906, as shown in table 3, but not the separate displacements. The separate displacements have been determined by interpolation from surrounding stations for the three points, Point Reyes Hill, Tomales Bay, and Bodega, as indicated in the discussion of group 1. The same process has also been applied to the seven points of group 4.

Starting with the interpolated displacements of 1868 for the three points, Point Reyes Hill, Tomales Bay, and Bodega, as shown in table 2, and with map 25 before one, it was a simple matter to interpolate separately the meridian components and the prime vertical components of the displacements of 1868 for the seven stations of group 4. This amounts practically to interpolating the displacements for these points from the three observed displacements of 1868 at Mount Tamalpais, Farallon Light-house, and Ross Mountain. The resulting interpolated displacements of 1868 are shown in table 2. Each of these being subtracted, component by component, from the corresponding combined displacement of 1868 and 1906, as shown in table 3, leaves the displacement of 1906 as shown in table 1.

A study of the possible accumulated errors in the triangulations shows that all of the seven displacements of 1906 in group 2 are certain except for Hans and Hammond. There is about one chance in five that the apparent displacements of 1906 for these two points are simply due to errors of observation.

The ten displacements of 1906 in this group show clearly the four laws already suggested in regard to such displacements. All points to the eastward of the fault moved southerly and those of the western side, northerly. Four of the five points to the westward of the fault moved in azimuths between 141° and 143° with a mean of 142° (38° W. of N.). The azimuth of this part of the fault is about 145° (35° W. of N.). The azimuth of the fifth displacement on the west side, at Bodega Head, is 172° (8° W. of N.). The azimuths of the three reasonably certain displacements of points to the eastward of the fault vary from 323° to 348° with a mean of 334° (26° E. of S.), which is within 9° of being parallel to the fault. Of the five points to the westward of the fault, the one nearest to the fault, Foster, has the greatest displacement. The other four, all between 2.0 and 2.7 kilometers from the fault, have nearly equal displacements. The five displacements for points to the eastward of the fault show a slight tendency to stand in inverse order from the distances from the fault. But one only of these displacements differs by more than 0.42 meter (1.4 feet) from the mean of the five, and the estimated distances from the fault vary only from 0.5 to 2.6 kilometers. When the uncertainty of the position of the fault beneath Tomales Bay is considered, as well as the small variation in distance of these ten points from the fault, difficulties are to be expected in detecting the relation between displacement and distance from the fault in this group. The mean displacement of the points to the eastward of the fault is 1.86 meters (6.1 feet) and of the five points to the westward 2.1 times as much, namely, 3.88 meters (12.7 feet).

Group 5. *Vicinity of Fort Ross.* — There are twelve points in this group, all determined by secondary triangulation in 1875–1876 and again in 1906, the scheme of triangulation being in each case substantially the same as that shown on map 25. The base from which these positions are determined is not independent of observations made before 1868, but is gotten by making the observations preceding that date conform to those made between 1868 and 1906. From the small size of the necessary corrections to the observed angles, and from the fact that the position of Ross Mountain, which predominates the group, is determined by observations made entirely after 1868, the error of assuming that these twelve points belong to the period between 1868 and 1906 is deemed negligible.

For one point, Chaparral, observations made in 1860 furnish a determination of the position before 1868, and hence the displacement of this point in 1868 (see table 2) is determined as well as its displacement in 1906. The displacement of 1868 agrees closely, within less than 0.13 meter (0.4 feet) in amount and 9° in direction, with the displacement at that time at Ross Mountain, 5.7 kilometers (3.5 miles) to the eastward.

A study of the possible accumulated errors in the triangulation shows that five of the observed displacements in this group, as referred to Mocho and Mount Diablo, are clearly beyond the range of possible errors of observation; namely, those at Fort Ross, Funcke, Timber Cove, Stockhoff, and Pinnacle Rock. For the remaining seven displacements, there are from one to two chances out of ten that they are due entirely to errors of observation, and these displacements are therefore reasonably certain. The relative displacements of pairs of points on opposite sides of the fault and near to each other in this group are certain, being in every case clearly beyond the range of possible errors of observation.

The apparent displacements in 1906 of the twelve points in this group conform closely to the four deduced laws governing such displacements. The seven points to the westward of the fault moved in a northerly direction, in azimuth varying from 137° to 158°, with a mean of 144° (36° W. of N.). The azimuth of the fault in this region is about 141° (39° W. of N.). All five points to the eastward of the fault moved southerly, in azimuth varying from 301° to 328° with a mean of 318° (42° E. of S.). All of the points in this group are within 3.2 kilometers (2.0 miles) of the fault and therefore give little opportunity to ascertain whether the amounts of the displacements show any relation to distances from the fault. Such a relation is not clearly discernible among the observed displacements. The evidence of the apparent displacement at Ross Mountain (see table 1), 6.2 kilometers (4.2 miles) to the eastward of the fault, indicates a decrease of displacement with increase of distance from the fault in that direction. The average displacement of the five points to the eastward of the fault is 1.44 meters (4.7 feet) and that of the seven points to the westward is 1.5 times as great, namely, 2.11 meters (6.9 feet).

Group 6. *Point Arena.* — In this group there are ten points determined by secondary triangulation in 1870 to 1892 that were redetermined by secondary triangulation in 1906, starting from the stations Fisher and Cold Spring, 11.2 and 13.5 kilometers eastward from the fault respectively. (See map 25.) A study of the possible errors in the triangulation shows that all of the observed displacements in this group are certain, each being clearly greater than the maximum possible errors of observation. There is a possibility that the assumption that the two stations, Fisher and Cold Spring, remained unmoved in 1906 is in error. The movement, if any, of these stations was probably about the same for both stations and in a southerly direction and parallel to the fault. If such a movement of these stations occurred, the computed displacements in 1906, shown in table 1 and on map 25, are all too small for stations to the eastward of the fault, and too great for stations to the westward of it.

The agreement of the observed displacements of the ten points in this group with the four deduced laws is close. The six points to the westward of the fault moved in azimuths varying thru a range of 5° only, from 159° to 164°, with a mean of 162° (18° W. of N.). The fault in this vicinity is said to change in azimuth, near the point where it crosses the coast-line, from about 144° to about 164° (16° W. of N.), curving to the eastward. The four points to the eastward of the fault moved in azimuths varying from 324° to 340° with a mean of 330° (30° E. of S.). The station Shoemake, comparatively near to the fault, 1.5 kilometers (0.9 mile), on the west side, showed a displacement much larger than any of the other five points on that side, all of which are from 5.7 to 7.6 kilometers from the fault. The two points to the eastward of the fault which are within less than 1 kilometer of it were displaced nearly twice as much as the other two which are nearly 4 kilometers from the fault. The average displacement for the four points to the east-

ward of the fault is 1.16 meters (3.8 feet) and for the six to the westward is 2.3 times as great, namely, 2.71 meters (8.9 feet).

Group 7. Southern part of primary triangulation. — In this group, extending southward from the line Mocho-Sierra Morena, there are nine points (see map 24) of which the positions were redetermined after the earthquake of 1906. Of these, one, Loma Prieta, had been formerly determined both before and after the earthquake of 1868; five others had been determined before 1868 but not after, and three had been determined after but not before 1868. (See tables 1 to 3.) In this group, therefore, but one point is available to show the displacement of 1868.

The triangulation of 1854–1855, starting from the line Ridge to Rocky Mound near the Pulgas Base, consisted of a single chain of triangles with all angles measured, down to the line Loma Prieta-Gavilan. The Point Pinos Light-house and the Point Pinos Latitude Station were connected with this chain, and with checks, by observations in 1854, 1864, and 1866.

The main triangulation of 1876–1887, from the line Mount Diablo-Mocho to the line Mount Toro-Santa Ana, consisted of a strong chain of figures with many checks, being substantially as shown on map 24 if Gavilan be omitted and all stations occupied. In this triangulation, however, no complete independent determinations with checks were made of Black Mountain, Santa Cruz Azimuth Station, Gavilan, Point Pinos Lighthouse and Point Pinos Latitude Station.

The triangulation of 1906–1907 was made as shown on map 24. Two separate least square adjustments were made of the main scheme connecting the points Mount Diablo, Mocho, Sierra Morena, Loma Prieta, Mount Toro, Gavilan, and Santa Ana.

In the first adjustment, it was assumed, as for the computations of other groups, that Mount Diablo and Mocho only remained unmoved during the earthquake of 1906. This first adjustment showed an apparent displacement of Santa Ana in 1906 of 3.26 meters (10.7 feet), in azimuth 288° (72° E. of S.), but an examination in detail of the possible accumulated errors in the triangulation showed that this apparent displacement was probably due to errors of observation. The new primary triangulation is much weaker in the figure defined by the five points, Mocho, Loma Prieta, Mount Toro, Gavilan, and Santa Ana, than elsewhere for two reasons. First, the length must be carried without a check thru the triangle Loma Prieta, Mocho, Mount Toro, of which only two angles were measured and this triangle is very unfavorable in shape for an accurate determination of length. Second, it so happened that the least accurate observations made in the primary triangulation were in this triangle or in its immediate vicinity.

In the second and adopted adjustment it was assumed that Santa Ana, as well as Mount Diablo and Mocho, remained unmoved during the earthquake of 1906. The astronomic azimuth had been observed at Mount Toro in 1885 and again after the earthquake of 1906. These two observations measured the absolute change in azimuth of the line between Mount Toro and Santa Ana and indicated it to be 2.5″, the later azimuth being the greater. This was utilized to strengthen the adjustment.

In view of the evidence of stations farther north, the assumption that Santa Ana remained unmoved is reasonably safe. Santa Ana is about 27 kilometers (17 miles) to the eastward from the point at which the fault disappeared near the village of San Juan. There is no station anywhere in the triangulation more than 6.4 kilometers to the eastward of the fault for which any displacement in 1906 was determined with certainty.

If Santa Ana was displaced in 1906, the erroneous assumption introduces an error into the computed displacements at the stations Gavilan, Mount Toro, Point Pinos Lighthouse, and Point Pinos Latitude Station, of about the same amount as the actual displacement at Santa Ana. The error produced in the computed displacement at Santa Cruz Light-house and Santa Cruz Azimuth Station must be much smaller, and no error

would be produced at Loma Prieta. Taking the uncertainty in regard to the estimated stability of Santa Ana into account as well as the possible errors in the triangulation, the following estimates of the uncertainties of the apparent displacements were made.

The displacements of Loma Prieta in 1906 and 1868 (see tables 1 and 2) are both certain.

The displacements of Black Mountain, Santa Cruz Azimuth Station, Gavilan, Point Pinos Light-house, and Point Pinos Latitude Station, as shown in table 3, are also certain. These are all combined displacements of 1868 and 1906. These stations were not determined between 1868 and 1906, hence it is not possible to determine directly from the observations the separate displacements. If it be assumed that the displacements in 1868 of the last four of these points were the same as that observed for Loma Prieta (see table 2), then the inferred displacements for each of these points in 1906 is as shown at the end of table 1. These inferred displacements for these points are, however, very doubtful as they depend upon a determination of the displacement of 1868 at a single point, Loma Prieta, which is 24 kilometers (15 miles) from Santa Cruz Azimuth Station and more than 48 kilometers (30 miles) from each of the other stations. It should be noted also that the displacement of Loma Prieta in 1868, which is certain, is very different from that of the other four points, Mount Tamalpais, Farallon Light-house, Chaparral, and Ross Mountain, for which the displacements of 1868 have been determined directly by observations. It is a displacement to the southward instead of to the northwestward and is much larger than for the other three points.

The determination of the displacement of Mount Toro as shown in table 1 is somewhat uncertain. There is still more uncertainty in regard to the apparent displacement at Santa Cruz Light-house.

The very small apparent displacement, 0.12 meter (0.4 foot), of the Lick Observatory small dome in 1906 is probably due to errors of observation.

The two points in this group to the eastward of the fault show apparent displacements in 1906 in accordance with the laws deduced from other groups: Lick Observatory, far from the fault, 36 kilometers (22 miles), having an apparent displacement so small as to be uncertain; and Loma Prieta, within 4.8 kilometers (3.0 miles) of the fault, having an apparent displacement of 0.97 meter (3.2 feet) in a southerly direction and within 9° of being parallel to the fault which here has an azimuth of about 312° (48° E. of S.).

Mount Toro is the only station to the westward of the fault in this group for which a determination of the displacement of 1906 is not very doubtful. The displacement in 1906 of 0.95 meter (3.1 feet) at Mount Toro is in a northerly direction with a slight inclination to the westward in fair agreement with the deduced laws. Mount Toro is beyond the end of the portion of the great fault of 1906 which has been traced on the surface.

The apparent displacement of Santa Cruz Light-house in 1906, of which the determination is doubtful, is closely parallel to the fault and in a northerly direction, corresponding to other points to the westward of the fault.

The inferred displacements of 1906 for four points shown at the end of table 1 are all very doubtful, and little significance should be attached to them or to the fact that they are somewhat contradictory to each other and all have a southerly tendency, whereas all other points to the westward of the fault of 1906 moved in a northerly direction. As a check on this conclusion, it should be noted that the inferred displacement for 1906 for Santa Cruz Azimuth Station differs by 72° in direction and 1.26 meters (4.1 feet) in amount from the observed displacement of 1906 for Santa Cruz Light-house, a point only 3.9 kilometers (2.4 miles) away. The observed displacement for Santa Cruz Light-house is much less uncertain than the inferred displacement for Santa Cruz Azimuth Station and hence the contradiction throws additional doubt on the latter and the other three points for which the inference is made in like manner.

Tho the inferred displacements of these four points for 1906 are all very doubtful, the observed combined displacements of 1868 and 1906 for these four points, as shown in table 3, are all certain, being clearly beyond the possible range of errors of observation. So also are the combined displacements of 1868 and 1906 for Loma Prieta and Black Mountain. It appears then that the combined effects of the earthquakes of 1868 and 1906 were to move the whole region from Black Mountain to Point Pinos to the southeastward by from 2.11 to 5.89 meters (6.9 to 19.3 feet). The mean azimuth of these six displacements is 321° (39° E. of S.). The most startling evidence of the combined effects of the two earthquakes is the increase of 3 meters (10 feet) in the width of Monterey Bay from Santa Cruz Azimuth Station to Point Pinos Light-house, both of these points having moved in a southerly direction, but the latter much more than the former. The length of the line Santa Cruz Azimuth Station to Point Pinos Light-house is only 39.8 kilometers (24.7 miles). The increase is therefore one part in 13,000.

Not much significance should be attached to the fact that Point Pinos Latitude Station has apparently moved one meter less than Point Pinos Light-house. This one meter is the difference of the combined displacements of two earthquakes. It is subject to the errors of observation in two determinations of each point by triangulation in somewhat different ways. Moreover, the determination of the position of the Latitude Station after the earthquake of 1906 was made without a check. It is for this reason that the displacement at Point Pinos Light-house is considered to be the more reliable determination of the two.

DISTRIBUTION OF EARTH MOVEMENT; SUMMARY.

In reaching the conclusions stated below, the evidence has been studied much more in detail than it has been given in the preceding pages. The conclusions are based on both the positive and negative evidence. The positive evidence is given by the displacements marked "certain" or "reasonably certain" in tables 1, 2, and 3. The negative evidence is given by displacements marked "doubtful," of which Rocky Mound is an example. At this point the observed apparent displacement of 1906 was only 0.34 meter (1.1 feet). The accuracy of the triangulation is such that it is practically certain that any displacement of this station as great as one meter would be detected. Hence the evidence given by this station is that the displacement, if any, was less than one meter and probably was less than 0.3 meter.

Maps 24 and 25 should be consulted while reading the following conclusions.

During an earthquake in 1868 or about that time, about 1,000 square miles of the earth's crust, comprized between the four stations Mount Tamalpais, Farallon Light-house, Ross Mountain, and Chaparral, were permanently displaced to the northward about 1.6 meters (5.2 feet), in azimuth 169° (11° W. of N.). The indications are that this whole area moved as a block without distortion or rotation; at least the triangulation furnishes no evidence competent to prove either distortion or rotation of the block (about a vertical axis), or to locate accurately any boundary of the block. It is probable that the block included Sonoma Mountain. It is reasonably certain that Rocky Mound and the group of points near the southern end of San Francisco Bay, Red Hill, Pulgas Base stations, and Guano Island, were not on this block, tho they were probably displaced somewhat irregularly during the earthquake of 1868.

During the earthquake of 1868, or about that time, Loma Prieta was permanently displaced about 3.03 meters (9.9 feet), in azimuth 307° (53° E. of S.). This displacement is in a direction at an angle of 138° with that of displacements of same date, referred to in the preceding paragraph. Loma Prieta moved to the southeastward, whereas Mount Diablo, Farallon Light-house, Ross Mountain, and Chaparral moved to the northward.

It is reasonably certain that Santa Cruz Azimuth Station, Point Pinos Light-house, Point Pinos Latitude Station, and Gavilan were similarly displaced. It is probable that the last

three stations named were displaced to the southeastward in 1868, being about 3 meters (10 feet) more than Santa Cruz Azimuth Station and Loma Prieta, and consequently the width of Monterey Bay was increased then by about one part in 13,000.

The combined effects of the earthquakes of 1868 and 1906 have increased the distance between Mount Tamalpais and Black Mountain, see map 24 and table 3, by 3 meters (10 feet). The distance is 79 kilometers (49 miles) and the increase is therefore one part in 26,000. The Golden Gate lies between these two stations. It is interesting to note that the length of part of the Pacific Coast including the Golden Gate has been increased just as the distance across Monterey Bay has been increased.

During the earthquake of April 18, 1906, displaced points on opposite sides of the great fault accompanying the earthquake moved in opposite directions, those to the eastward of the fault in a southerly and those to the westward in a northerly direction. Among all the points there are but two apparent exceptions to this rule, namely, Rocky Mound and Red Hill. For both these stations the apparent exceptional movement is so small as to be probably due simply to errors of observation and therefore it is not significant.

During the earthquake of 1906, the permanent displacements of all disturbed points were approximately parallel to the fault. When the difficulties encountered in determining the direction of these displacements are considered, it is remarkable that the observed displacements follow this law so accurately as they do. The nearest fixt points to which each displaced point is referred are from 30 to 140 kilometers distant (20 to 90 miles). The total displacements are from 0.5 to 4.6 meters (2 to 15 feet). Among all the points examined, there are but five for which the apparent changes in distance from the fault are not so small as to be probably due to errors of observation. The Farallon Light-house apparently moved at an angle of about 27° with the fault and its increase in distance from the fault of 0.8 meter is reasonably certain. As Mount Tamalpais, nearly opposite to Farallon Light-house across the fault, moved practically parallel to the fault, there was either an opening of the fault beneath the sea in this region or an increase in length of the earth's crust, in a direction at right angles to the fault, of one part in 50,000 (0.8 meter on 44 kilometers, or 3 feet on 27 miles). Point Reyes Light-house also apparently receded from the fault, moving in about the same direction (within 5°) as the Farallon Light-house, but the determination of the displacement of the Point Reyes Light-house is so weak that this apparent displacement has little significance. It is reasonably certain that Bodega Head approached the fault from the western side, while Bodega, on the eastern side of the fault, about opposite, moved parallel to the fault. The apparent closing up of the fault or shortening of the crust at right angles to the fault is 1.6 meters (5.2 feet) between these two points only 5.4 kilometers (3.4 miles) apart. This is one part in 3,400. It is possible that as much as one-half of this apparent closing up is due to errors of observation, but it is reasonably certain that not all of it is due to that cause. Similarly it is reasonably certain that Peaked Hill in the Fort Ross group receded from the fault on the east side and Pinnacle Rock approached it on the west side, the apparent amounts being 0.4 meter (1.3 feet) and 0.7 meter (2.3 feet) respectively. It is reasonably certain that San Pedro Rock in the Colma group approached the fault from the west side, the apparent amount being 1.1 meters (3.6 feet).

During the earthquake of 1906, the displacements on each side of the fault were less the greater the distance of the displaced points from the fault. On the eastern side of the fault, ten points at an average distance of 1.5 kilometers (0.9 mile) from the fault have an average displacement of 1.54 meters (5.1 feet); three points at an average distance of 4.2 kilometers (2.6 miles) have an average displacement of 0.86 meter (2.8 feet), and one point, Mount Tamalpais, at 6.4 kilometers (4.0 miles) from the fault, has a displacement of 0.58 meter (1.9 feet). These fourteen points are the only ones on the eastern side of the fault for which the observed displacements were determined with reasonable certainty. For no point to the eastward of the fault at a greater distance than 6.4 kilometers (4.0

miles) was any displacement detected with certainty. To the westward, twelve points at an average distance of 2.0 kilometers (1.2 miles) from the fault have an average displacement of 2.95 meters (9.7 feet). Seven at an average distance of 5.8 kilometers (3.6 miles) have an average displacement of 2.38 meters (7.8 feet). The only other point to the westward of the fault of which the displacement was determined with certainty was Farallon Light-house, distant 37 kilometers (23 miles) and displaced 1.78 meters (5.8 feet).

In receding from the fault, either to the eastward or to the westward, the displacement decreases more rapidly near the fault than it does farther from the fault. According to the averages given in the preceding paragraph, the decrease in displacement on the eastern side near the fault is at the rate of 0.25 meter per kilometer (that is, 0.68 meter on 2.7 kilometers) and farther away the rate is 0.13 meter per kilometer (that is, 0.28 meter on 2.2 kilometers). Imagine a straight line before the earthquake of April 18, 1906, starting at the fault and extending eastward at right angles to it. According to this investigation, after the earthquake this line became a curved line concave to the southward, the point at the fault being displaced southward and distant points on the line remaining fixt. Also according to the above figures, the part of the line which is from 1.5 to 4.2 kilometers from the fault was deflected from its former direction about 52 seconds and that part from 4.2 to 6.4 kilometers from the fault was deflected about 26 seconds, and the deflection probably decreased gradually to zero at distant points. To the westward of the fault the rate of decrease of displacement, according to the averages in the preceding paragraph, near the fault is 0.15 meter per kilometer (that is, 0.57 meter on 3.8 kilometers), and farther away only 0.02 meter per kilometer (that is, 0.60 meter on 31 kilometers). Accordingly the imaginary straight line at right angles to the fault and extending westward from it has become concave to the northward, the point at the fault being displaced to the northward and very distant points remaining fixt. The deflection from its original direction is about 31 seconds for the part from 2 to 6 kilometers from the fault and about 4 seconds on an average for the part from 6 to 37 kilometers from the fault.

For points on opposite sides of the fault of 1906, and at the same distance from it, those on the westward side are displaced on an average twice as much as those on the eastern side. This statement applies especially to points within 10 kilometers (6 miles) of the fault. For points farther away, the ratio becomes more than two to one. It is important to note that this statement applies to displacements, not distortions. The distortion, exprest in angular measure, discust in the preceding paragraph, is nearly the same on the two sides of the fault, being somewhat less close to the fault on the western side than on the eastern side.

The amount of relative displacement of the two sides of the fault by sliding along the fault, as detected by the triangulation, shows no variations for different parts of the fault along its whole length from Point Arena to San Juan, with one exception, which are sufficiently large to be clearly not due to errors of observation. This exception is the region near Colma where, as already noted, relative displacements seem to be unusually small.

The permanent displacements and distortions which took place at the time of the earthquake of April 18, 1906, may be pictured by imagining a series of perfect squares drawn on the surface of the ground before the earthquake, with their sides parallel and perpendicular to the fault. At the time of the earthquake every square to the eastward of the fault moved bodily in a southerly direction parallel to the fault, the squares more distant from the fault moving less than those near to it. All sides of squares parallel to the fault remained straight lines, unchanged in length and direction. For the squares to the eastward, the sides perpendicular to the fault became curved lines concave to the southward and changed direction as a whole by rotation in a counterclockwise direction, the change being 52 seconds or more for squares near the fault, and less for more remote squares. The angles of the squares all took new values differing from 90° by quantities

ranging from more than 52 seconds to zero. The squares to the westward of the fault were moved bodily in a northerly direction parallel to the fault, their sides parallel to the fault remaining straight and unchanged in length and direction. Their sides perpendicular to the fault became curved lines concave to the northward and each changed in direction by rotation in a counterclockwise direction, the change being more than 31 seconds for squares near the fault and less for more remote squares. The displacement of squares near the fault was twice as great for squares on the western side as for squares on the eastern, but the distortion was slightly less for squares on the western side than for those on the eastern side. The appreciable displacements extended back much farther from the fault on the western side than on the eastern side.

It is not probable that the actual displacements and distortions were perfectly regular as indicated in the word picture of the preceding paragraph, but the apparent departures from this perfectly regular ideal, of the displacements and distortions detected by the triangulation are nearly all so small as to be possibly due to errors of observation. Attention has been called to the few exceptions, of which one can be certain, which have been detected. The earth-movements of April 18, 1906, were remarkable for their regularity of distribution.

The triangulation of 1906–1907 has extended eastward clearly beyond the region of appreciable permanent displacements by the earthquake of 1906. The disturbed region evidently extended to the westward out under the Pacific beyond the possible reach of the triangulation. To the northward of Point Arena there is little probability of much success if an attempt were made to determine additional displacements by triangulation, for the known fault of 1906 touches the coast for but a short distance anywhere north of Point Arena, and triangulation to the northward of Point Arena before the earthquake consisted simply of a narrow and weak belt of tertiary triangulation. It had been intended to extend the triangulation of 1906–1907 far enough to the southward to reach outside of the disturbed region. It was supposed until after the observing party left the southern end of the triangulation that this had been accomplished, but when the additional evidence given by the office computations became available, it was evident that the most southern points determined are still within the disturbed region. The fact that the visible evidence of the fault of 1906 does not extend farther southward than San Juan indicates that there are probably few points to the southward of Mount Toro and Point Pinos for which the displacements were large enough to be detected by triangulation.

DISCUSSION OF ASSUMPTIONS.

Certain things have apparently been assumed in this investigation; for example, that appreciable permanent displacements occurred during the earthquake of 1868 as well as during the earthquake of 1906; that the permanent displacements in 1906 occurred suddenly, and that the stations Mocho and Mount Diablo remained unmoved in both earthquakes.

These are called apparent assumptions because in a real sense they are not assumptions but are instead facts detected gradually in studying for fifteen months upon a steadily increasing mass of evidence. However, treating them as assumptions, their validity has been reëxamined in the light of all the evidence, and to make this report complete, it is now necessary to state why they are believed to be true.

It has been tacitly assumed that the permanent displacements of 1906, detected by the triangulation, took place suddenly. It is certain from evidence entirely distinct from the triangulation that on April 18, 1906, relative displacements by sliding along the great fault of that date took place suddenly, that is, within an interval of a few seconds, without much crushing or separation of the sides of the fault, and that these relative displacements

amounted from 2 to 6 meters (7 to 20 feet). These relative displacements were evident at every road, fence, or line of trees crossing the fault, but such evidence does not enable one to ascertain how far back from the fault in each direction the displacement extended. The repetition of the triangulation after the earthquake showed that many points at various distances from the fault had all been displaced parallel to the fault, that the distribution of the displacements is regular, and that for points nearest the fault, the relative displacements corresponded in amount to those observed at roads, fences, tree lines, etc., at the fault and which were known to have taken place suddenly. Hence it is certain that the widely distributed displacements shown by the triangulation are a part of the same phenomenon and took place at the same time as the displacements at the fault, that is, suddenly on April 18, 1906.

For the displacements credited to the year 1868 in this report, the case is different. It had been known from previous examination of the evidence given by triangulation that Mount Tamalpais had moved between 1859 and 1876. In the course of the detailed studies of the triangulation in connection with the present investigation, it was found that other triangulation stations had moved at or about 1868. It was discovered that wherever triangulation in this part of California before 1868 had been connected with triangulation done after 1868, it was necessary, in order to obtain consistent results, to apply abnormally large corrections to the observed angles. By trial it was found that wherever the observations of angles were separated into two groups and separate computations made connecting identical points marked upon the ground, one group comprizing observations before 1868 and the other observations after that year, that the corrections necessary to obtain consistent results from each set of angles were much smaller than before, and about the normal size to be expected from the instruments and methods of observation used. The evidence proves that permanent displacements took place at or about 1868 of a magnitude which the triangulation could detect with certainty. The particular year in which the displacements took place is not fixt, however, by the triangulation, but simply the fact that they occurred within the interval of several years which elapsed in each part of the triangulation between the last observation before 1868 and the first observation after that year. For this reason considerable care has been taken in stating the dates of the triangulation for each locality. In 1906, it was known that sudden permanent displacements took place on a certain day, hour, and minute along a great fault-line and these displacements were similar to those detected later by triangulation. So far as the writers know, no evidence has been found that such large sudden relative displacements took place in 1868 or about that year, but it is known that a very severe earthquake in this region occurred in 1868. Hence the observed displacements, referred in this report to 1868 for the sake of brevity, may have occurred in some other year near 1868 and may have occurred by a gradually creeping motion extending over several years.

No other abnormal discrepancies in the triangulation within this region are known to exist. If there are such discrepancies, produced by displacements of the triangulation stations by earthquakes, they are so small as to be effectually masked by the unavoidable errors of observation. In other words, any other permanent horizontal displacements by earthquakes within this region between 1850 and 1907 must have been much smaller than the displacements of 1906 and 1868.

It has been assumed that there was no permanent displacement of stations Mocho and Mount Diablo during the earthquake of 1906. What is the evidence that this assumption is true?

The true direction or azimuth from Mocho to Mount Diablo was determined by observations upon the stars in 1887 and found to be 144° 57′ 35.71″. In 1907 it was redetermined by observations upon the stars and found to be 144° 57′ 35.66″, differing by only 0.05″

from its former value. The maximum possible difference between the two determinations of azimuth which could occur simply as errors of observation is about 1″.[1] Hence these observations show positively that the true direction from Mocho to Mount Diablo had not changed between these dates by as much as 1″ and probably had not changed by as much as 0.3″.

The true direction or azimuth of the line Mount Tamalpais to Mount Diablo was determined by observations upon the stars in 1882 and again in the same manner in 1907. In 1882 it was found to be 274° 15′ 15.04″ and in 1907, 274° 15′ 14.49″, 0.55″ less than before. The azimuth of the line Mount Tamalpais to Mount Diablo was computed separately from the triangulation between 1868 and 1906, and from the triangulation after the earthquake of 1906 and the two values found to be 274° 15′ 19.46″ and 274° 15′ 17.89″ respectively, the second being 1.57″ less than the first. This apparent decrease of azimuth as determined by the triangulation agrees within 1.02″ with the decrease of 0.55″ determined independently by astronomic observations.[2] This agreement is within the range of possible errors of observation. In the two computations of the triangulation, the line Mocho-Mount Diablo was assumed to have the same azimuth before and after April 18, 1906; hence the close agreement noted indicates that the azimuth Mocho-Mount Diablo remained unchanged.

In the investigation which has been made, it was found that the absolute displacement decreased with increased distance from the fault and that no displacement sufficiently large to be detected with certainty was found farther to the eastward of the fault than Mount Tamalpais, 6.4 kilometers (4.0 miles) from it. Mocho and Mount Diablo are 53 kilometers (33 miles) from the fault; hence it seems certain that the displacements, if any, at Mocho and Mount Diablo must have been extremely small. It may be objected that this is reasoning in a circle, inasmuch as the computed displacements depend upon the assumption that Mocho and Mount Diablo stood still. Cleared of this objection, the argument reduces to the following. The triangulation shows no relative displacements in 1906, large enough to be determined with certainty, of Mocho, Mount Diablo, Rocky Mound, Red Hill, and Lick Observatory, a group of points far to the eastward of the fault, whereas many points nearer to the fault showed large relative displacements as referred to each other, with a marked tendency to be greater the nearer to the fault are the groups of points compared. Hence the reasoning is valid that Mocho and Mount Diablo remained unmoved, these being two points in a group showing no displacements relative to each other, the whole group being far from the fault and these two particular stations being the two points most distant from the fault.

If either Mocho or Mount Diablo had moved in April, 1906, in such a direction as to decrease (or increase) the azimuth of the line joining them, the effect of the erroneous assumption, used in the computation of the triangulation done after the earthquake that the azimuth had remained unchanged, would have been to produce a set of computed apparent displacements which would be represented by red arrows on map 24, all indicating a rotation in a clockwise (or counterclockwise) direction around Mount Diablo, the lengths of the arrows being proportional to their distances from Mocho and Mount Diablo. The fact that the computed apparent displacements of 1906, as shown by the red arrows on maps 24 and 25, do not show any such systematic relation to each other, indicates that the line Mocho-Mount Diablo remained unchanged in azimuth on April 18, 1906.

[1] The probable error of observed azimuth in 1887 was ± 0.21″ and in 1907 ± 0.20″. The expression "probable error" is here used in the technical sense in which it is used in connection with the least square method of computation.

[2] The discrepancy of about 4″ on each date between the azimuth determined by astronomic observations and the azimuth determined by triangulation is what is known as "station error" in azimuth and is due to the deflection of the vertical at the observation station. It does not enter into the present discussion, which is based on differences of azimuths of the same kind, either astronomic or geodetic, on different dates at the same station.

Similarly, if either Mocho or Mount Diablo had moved on April 18, 1906, in such a direction as to increase (or decrease) the distance between them, the effect upon the computations of apparent displacements would have been to produce a set of red arrows on maps 24 and 25, all pointing toward (or from) Mocho and Mount Diablo, the lengths of the arrows being proportional to their distances from Mocho and Mount Diablo. No such systematic relation appears among the arrows.

Another item of evidence is still available which indicates that the absolute displacement of points far to the eastward of the fault was zero on April 18, 1906. From 1899 to date a series of observations of latitude by observations upon the stars has been in progress continuously for the International Geodetic Association at Ukiah, California. The purpose of these observations is to detect variations in latitude due to any cause. The observations are of an extremely high grade of accuracy and they are made on every clear night. Dr. S. D. Townley, in charge of these observations, made a special study of the 233 observations made during the interval April 4–May 4 inclusive, 1906, to determine whether any sudden change of latitude took place on April 18.[1] He found no such change. The observations are competent to determine with reasonable certainty any change as great as 0.03″, corresponding to 1 meter (3 feet). It is therefore reasonably certain that the southward component of the motion, if any, of the pier on which Dr. Townley's latitude instrument was mounted at Ukiah, was less than one meter on April 18, 1906. Ukiah is about 42 kilometers (26 miles) from the fault and to the eastward of it. Mocho and Mount Diablo are much farther from the fault (53 kilometers). It is important to note that latitude observations determined the absolute displacement rather than the relative displacement and that they are independent of observations at any other station.

For the reasons set forth above, it is believed to be certain that the permanent displacement, if any, of either Mocho or Mount Diablo on April 18, 1906, must have been extremely small.

During verbal discussions of the earthquake of April 18, 1906, it has been suggested more than once that one of its possible effects may have been to change the position of the earth with relation to its axis of rotation and so produce a change of latitudes. If an appreciable effect of this kind were possible, the validity of the above reasoning in regard to the latitude observations at Ukiah would be questionable. Accordingly, a computation of this possible effect has been made.[2] It was found that if it be assumed that the mass displaced in a northerly direction to the westward of the fault comprized 40,000 square kilometers (15,600 square miles) of the earth's crust, having a mean latitude of 38° and thickness or depth of 110 kilometers (68 miles), that this material had an average density of 4.0 and that the northerly component of the displacement was 3 meters (10 feet), the position of the pole of maximum moment of inertia would be displaced by 0.0007″, corresponding to 0.002 meter (0.006 foot). This is a limiting value certainly much larger than the actual value, for all assumptions entering the computation as to the area, depth, density, amount of displacement, and mean latitude have been made such as to make the computed value certainly too great. Moreover, the similar displacements of contrary direction to the eastward of the fault would partially cancel those on the westward side which have been considered. When the pole of maximum moment of inertia is displaced, the pole of rotation is not immediately changed with reference to the earth. The pole of rotation tends always to seek the pole of maximum moment of inertia and travels around it in an irregular path. It is the instantaneous position of the pole of rotation with reference to the earth which fixes the latitude at any instant. Hence

[1] This investigation is published in the Publications of the Astronomic Society of the Pacific, Vol. XVIII, No. 109, Aug. 10, 1906, under the title The Latitude of the Ukiah Observatory before and after April 18, 1906.

[2] The formula and method of computation is shown in Traité de Mécanique Céleste, par F. Tisserand, Paris, 1891, Gauthier-Villars, Tome II, pp. 485–487.

even this extremely small displacement of the pole of maximum moment of inertia computed above, 0.002 meter, does not immediately affect the latitude of points in California, but only tends to change them by that average amount in the course of a year or more. The effect of the earthquake on the latitudes of points outside the region of actual displacement of the surface is therefore entirely negligible. The earthquake changed the latitude of marked points on the earth's surface within the disturbed region by the amount of the northward or southward components of the displacement of the points.

Similarly, the possible effect of the displacements on the deflections of the vertical, that is, upon the direction of gravity at any point, is too small to be considered.

The displacements near Point Arena were computed upon the assumption that the triangulation stations Fisher and Cold Spring remained unmoved during the earthquake of 1906. Is this assumption true? The station farthest to the eastward from the fault at which a displacement in 1906 has been detected with certainty is Mount Tamalpais, distant 6.4 kilometers and displaced 0.53 meter. Also the rate of decrease of displacements at this distance has been found to be 0.13 meter per kilometer of increase of distance from the fault. At this rate, the displacement would become zero at about 11 kilometers from the fault. Fisher is 11.2 and Cold Spring 13.5 kilometers from the fault; hence it is reasonably certain that if the displacement was not zero, at these two stations, it was so nearly zero that it could not have been detected with certainty.

A high degree of accuracy has been claimed for the triangulation. There is abundant evidence available from which to determine the actual accuracy, as has been indicated in an earlier part of this report. A large amount of time has been spent in studying this evidence in order to insure that the estimates of the accuracy of the determination of the various apparent displacements might be reliable. The methods necessarily followed in estimating the accuracy are too technical and too complicated to be included in this report. Two illustrations of the degree of accuracy attained in the observations may prove interesting, however.

The position of the Lick Observatory small dome was determined after the earthquake of 1906 by intersections upon it from four stations, Loma Prieta, Sierra Morena, Red Hill, and Mocho. There were discrepancies among these observations which were adjusted by the method of least squares and a resulting most probable position adopted and used in computing the apparent displacement given in table 1. The mean observation from Loma Prieta hit 0.38 meter (1.2 feet) to the left of the position adopted for the dome. The mean observation from Sierra Morena hit 0.22 meter (0.7 foot) to the right, that from Red Hill 0.01 meter (0.03 foot) to the left, and that from Mocho 0.11 meter (0.4 foot) to the left of the adopted position. The words "right" and "left" refer in each case to the Lick Observatory dome as seen from the station named. The distance of the four observation points from the Lick Observatory were, Loma Prieta 31 kilometers (19 miles), Sierra Morena 59 kilometers (37 miles), Red Hill 46 kilometers (29 miles), and Mocho 17 kilometers (11 miles).

Similarly the determination of the position of the Lick Observatory before the earthquake depended upon observations taken from seven stations, Santa Ana, Mount Toro, Loma Prieta, Sierra Morena, Mount Tamalpais, Mount Diablo, and Mocho. The line from Mount Tamalpais, 106 kilometers (66 miles) long, mist the adopted position by 0.36 meter (1.2 feet). The other six all came nearer than this to the adopted position.

The Farallon Light-house was determined between 1868 and 1906 by intersections upon it from three stations, Mount Helena, Mount Tamalpais, and Sierra Morena. The mean observation from Mount Helena, distant 112 kilometers (70 miles), mist the adopted position by 0.30 meter (1.0 foot) and the other two lines came closer. In 1906–1907 the Farallon Light-house was determined by intersections upon it from the six stations Ross Mountain, Tomales Bay, Point Reyes Hill, Sonoma, Mount Tamalpais, and Sierra Mo-

rena. The line from Sonoma, 79 kilometers (49 miles) long, mist the adopted position by 0.10 meter (0.3 foot) and all the others came closer.

One other assumption remains to be examined. The displacements of 1868 were computed on the assumption that the line Mount Tamalpais to Mount Diablo had a certain length and azimuth before 1868 and a certain different length and azimuth after 1868; Mount Tamalpais being supposed to be in a new position, but Mount Diablo unmoved. The two positions for Mount Tamalpais were derived from certain computations based in turn on assumptions that certain other stations remained unmoved in 1868, or practically so.

The azimuth of the line Mount Tamalpais to Mount Diablo was determined by observations upon stars in 1859, and again in 1882; the later observations made the azimuth 7.84″ greater than earlier observations. The two adopted azimuths from the computations of triangulation referred to above also differ by 5.38″, the later adopted value being the greater.

The fact that the two independent determinations of change of azimuth, one astronomical and one geodetic, agree within 2.46″ is a strong proof that the adopted geodetic azimuths are correct, 2.46″ being within the possible range of the various observations.

Following the same reasoning as for Mocho and Mount Diablo, the computed displacements of 1868, as shown by red arrows on maps 24 and 25, indicate that the two azimuths and two lengths used for the line Mount Tamalpais to Mount Diablo, before and after 1868, must be very close to the truth.

CHANGES IN ELEVATION.

The preceding portions of this Report have dealt with permanent horizontal displacements caused by the earthquake of 1906. It is important to know whether permanent displacements in the vertical sense also occurred. Upon this point the observations of the Coast and Geodetic Survey furnish evidence for a small area, involving parts of San Francisco, both sides of the Golden Gate, and Sausalito, 1.25 miles north of the Golden Gate.

At the time of the earthquake an automatic tide-gage was in operation at the Presidio Wharf, in San Francisco, on the southern side and about 1.25 miles to the east of the narrowest part of the channel thru the Golden Gate. The gage had been in operation at that point continuously since July 17, 1897, and is still in operation.

The record made by this gage on April 18, 1906, showed an oscillation, with a range of about six inches, in the water surface evidently produced by the earthquake, but it showed no evidence of a change in the relation of the gage zero to mean sea-level. In other words, the record for that day does not indicate that the tide-staff had been changed in elevation by the earthquake.

To detect any possible small change in elevation it is, of course, necessary to examine much more record than that for a single day. The examination has now been extended by computation to include a whole year of observations since the earthquake for comparison with nine years of observations before it.

The following table shows the reading of mean sea-level on the fixt tide-staff for each of ten years, as determined by taking the mean of the hourly ordinates of the tidal curve. The annual means are taken rather than means for any other period in order to eliminate annual inequalities, presumably due to meteorological causes, which affect the means for separate months. May 1 is taken as the beginning of the complete year available after the earthquake. Since it is not convenient, in the computation, to separate any month's observation into two parts, the year is commenced on May 1, rather than on April 18, the date of the earthquake. The first year, 1897–1898, is incomplete because the observations were not commenced until July 17, 1897.

Table 4. — Readings of Mean Sea-level on the Fixt Tide-staff.

Period	Reading of Mean Sea-level on Tide-staff	Means
	Feet	
July 17, 1897 to Apr. 30, 1898	8.339	8.318
May 1, 1898 to Apr. 30, 1899	8.298	
May 1, 1899 to Apr. 30, 1900	8.528	
May 1, 1900 to Apr. 30, 1901	8.550	
May 1, 1901 to Apr .30, 1902	8.430	8.520
May 1, 1902 to Apr. 30, 1903	8.584	
May 1, 1903 to Apr. 30, 1904	8.509	
May 1, 1904 to Apr. 30, 1905	8.667	
May 1, 1905 to Apr. 30, 1906	8.659	8.652
May 1, 1906 to Apr. 30, 1907	8.631	

The ten annual means show an unmistakable tendency to fall into three groups, as indicated by the means shown in the last column of the table. Within each group there is no apparent tendency to increase or decrease. Between the first and second groups the reading of mean sea-level increased 0.202 foot and between the second and third groups, it again increased 0.132 foot. Such an increase corresponds to a subsidence of the zero of the tide-staff with reference to mean sea-level. An examination of the monthly means indicates that probably the subsidence occurred suddenly in each case, the movements taking place about June, 1899, and April, 1904. The record must not be considered as proving positively that these two subsidences took place. The changes are not clearly beyond the range of possible error in the determination of mean sea-level on account of irregular changes in the water surface due to causes not clearly understood, tho they are beyond the possible range of instrumental errors.

The annual mean for the one year after the earthquake, 1906–1907, agrees with the two preceding annual means within less than 0.04 foot. In no other case in the table do three successive annual means agree so closely with each other as these three. Apparently, therefore, no change in the elevation of the zero of the tide-staff occurred at the time of the earthquake.

As further evidence that no appreciable change in the elevation of the tide-staff took place on April 18, 1906, the following table is submitted. Corresponding months of two years, one before and one after the earthquake, are compared to avoid the effects of annual inequalities. The comparison indicates that no change took place in April, 1906.

Table 5. — Monthly Mean Readings of Mean Sea-level on Tide-staff.

	1905–1906	1906–1907	Difference
	Feet	Feet	
May	8.507	8.462	+ .045
June	8.416	8.506	− .090
July	8.668	8.688	− .020
August	8.676	8.797	− .121
September	8.648	8.632	+ .016
October	8.690	8.442	+ .248
November	8.751	8.295	+ .456
December	8.479	8.625	− .146
January	8.701	8.784	− .083
February	8.877	8.725	+ .152
March	8.934	8.944	− .010
April	8.558	8.669	− .111
		Mean =	+ .028

The zero of the tide-staff was connected by leveling with the group of bench-marks near the gage at various times during the interval 1898–1907, including a determination after the earthquake. The leveling showed no appreciable change in the relation in elevation of the bench-marks and the tide-staff. Hence, the preceding statements in regard to a possible subsidence of the tide-staff on two occasions and in regard to its constancy of elevation on April 18, 1906, also apply to this group of bench-marks.

Before the earthquake the Coast and Geodetic Survey had done leveling which connected the gage at the Presidio Wharf with various bench-marks in San Francisco from Fort Point to the Union Iron Works, and with bench-marks at Sausalito. This leveling was not of the grade of accuracy known as precise leveling nor was it done continuously. There are also available for use in the present investigation certain relative elevations of bench-marks before the earthquake furnished to the Coast and Geodetic Survey by the city engineer of San Francisco. These include a bench-mark near the gage at the Presidio Wharf.

After the earthquake Mr. B. A. Baird, Assistant, Coast and Geodetic Survey, ran a line of precise levels from the Presidio gage to Fort Point and Sausalito, and to the eastward thru San Francisco, to the Union Iron Works, connecting with various old bench-marks.

There were 26 bench-marks connected by the leveling before the earthquake which were recovered with certainty by Mr. Baird and the elevations redetermined by him. The following table shows the elevations of these bench-marks before and after the earthquake and their apparent changes in elevations. All of the elevations in the table are referred to the same datum, which is the reading 8.514 feet (2.5951 meters) on the fixt tide-staff at the Presidio Wharf, that being approximately mean sea-level. All the elevations are computed on the supposition that the zero of the tide-staff at the Presidio Wharf remained unchanged at the time of the earthquake.

The table shows no appreciable change of elevation of the bench-marks at the Presidio Wharf. The maximum apparent change in elevation is 7.0 mm. (0.3 inch), a quantity within the possible range of error of the leveling. Mr. G. K. Gilbert, Geologist of the U. S. Geological Survey, at the close of an examination made soon after the earthquake and before the leveling had been done, exprest the opinion that if this group of bench-marks had not changed their relative elevations, they probably had not changed in relation to the tide-staff. It is probable, therefore, that these two bench-marks and the tide-staff maintained their absolute elevations unchanged.

At Fort Point, the three bench-marks near the shore show an apparent rise of 74 mm. (2.9 inches) on an average, and bench-mark 9, high up on Fort Point, shows a slightly smaller apparent rise, 59 millimeters (2.3 inches). All these are on ground supposed to be stable. The rise indicated by the city leveling, in the last column, is considerably smaller.

The two bench-marks at Sausalito show an apparent rise of 37 millimeters (1.5 inches). It is not certain that this represents a real change in elevation as referred to the zero of the Presidio tide-staff. The errors of the old and new leveling, including the crossing of the Golden Gate (about 1.25 miles) in each case, may account for the apparent change. In the leveling before the earthquake the elevation was transferred from Presidio to Sausalito by water-levels and also by wye leveling with a difference of 13 millimeters (0.5 inch). In the precise leveling after the earthquake, the two independent crossings of the Golden Gate, each depending on many hours of observation, differed by 30 millimeters (1.2 inches).

The three bench-marks at and near Fort Point showed small apparent changes in elevation.

From an examination made soon after the earthquake Mr. G. K. Gilbert, Geologist, exprest the opinion that the bench-marks at Lafayette Park were probably more stable

Table 6. — Elevations of bench-marks before and after the earthquake.

Locality	Character of Bench-Mark	B. M.	Elevations: After Earthquake Coast and Geodetic Survey 1906–1907	Elevations: Before Earthquake: Coast and Geodetic Survey 1877–1905	Elevations: Before Earthquake: City Levels 1901–1906	New-Old (Coast and Geodetic Survey)	New-Old (City)
			Meters	*Meters*	*Meters*	*Mm.*	*Mm.*
Presidio Wharf.......	Zero of tide-gage	11	– 2.5951	– 2.5951	....	0.0	....
	Hinge socket of door of brick warehouse.	12	3.8932	3.9002	3.9002	– 7.0	– 7.0
	Copper bolt in granite post.	15	2.7426	2.7371	....	+ 5.5	....
Fort Point	Copper bolt in natural rock.	4	6.7585	6.6797	....	+ 78.8	....
	Copper bolt in granite post.	5	14.7958	14.7237	....	+ 72.1	....
	Copper bolt in granite sea-wall.	6	3.9275	3.8554	3.8895	+ 72.1	+ 38.0
	Brass plate on concrete emplacement.	9	60.7745	60.7151	60.7232	+ 59.4	+ 51.3
Sausalito	Copper bolt in rock ...	2	1.3909	1.3564	....	+ 34.5	....
	Granite post	3	11.6073	11.5672	....	+ 40.1	....
Van Ness and Lombard Aves.	Star on iron plate in street.	27B	29.4047	....	29.3967	....	+ 8.0
Fort Mason...........	Granite post	28	32.5727	32.5606	32.5493	+ 12.1	+ 23.4
Fort Mason...........	Granite post	29	31.0876	31.0854	31.0649	+ 2.2	+ 22.7
Lafayette Park	Granite post	24A	101.7846	....	101.7412	....	+ 43.4
	Pendulum pier	25	113.9662	114.0414	....	– 75.2	....
	Transit pier	27	115.3477	115.4222	....	– 74.5	....
Union Iron Works	Brass spike in brick bldg.	50	3.7860	3.8384	....	– 52.4	....
	Window shutter socket	47	4.4482	4.4004	4.4299	+ 47.8	+ 18.3
	Bolt in wall of bldg....	48	6.2121	6.1695	....	+ 42.6	....
19th and Bryant Sts...	Copper bolt in brick bldg.	58	13.6176	13.5889	13.5883	+ 28.7	+ 29.3
Magdalen Asylum, Potrero Ave.	Copper bolt in brick bldg.	61	23.3281	23.3063	23.2977	+ 21.8	+ 30.4
Appraisers' Bldg......	Iron Rod	40B	3.3068	....	3.3241	....	– 17.3
Potrero Ave. and Division St.	Fire hydrant..........	44I	5.9000	....	5.9695	....	– 69.5
17th and Carolina Sts.	Nail in doorstep	City	6.0238	....	5.9978	....	+ 26.0
Mariposa St. between Penn. and Iowa Sts.	Bolt in concrete on bridge over S. P. tracks.	S. P.	10.4666	....	10.4110	....	+ 55.6
Cal. and Montgomery Sts.	Water table of Parrott Bldg.	41	5.1488	5.0173	....	+ 131.5	....
East and Mission Sts.	Iron pillar of brick bldg.	43	2.4828	2.8523	....	– 369.5	....
Folsom between Main and Beale Sts.	Granite post set in brick wall.	44	5.4835	5.5516	....	– 68.1	....

than any of the others examined by him. The table indicates that the two of these bench marks, formerly determined by the Coast and Geodetic Survey leveling, subsided 75 millimeters (3.0 inches) and that the one, determined by the city leveling, rose 43 millimeters (1.7 inches). There is no apparent reason for the contradiction among the three bench-marks of this group.

For the three bench-marks at the Union Iron Works, the table shows a contradiction, two of them having, apparently, increased in elevation and one having decreased. The greatest change is, however, only 52 mm. (2.0 inches). The Union Iron Works is said to be partly on filled ground.

The two bench-marks near the Magdalen Asylum apparently increased in elevation as shown by both the Coast and Geodetic Survey and city leveling.

Of these bench-marks, the thirteen in the five groups at Fort Point, Sausalito, Fort Mason, Union Iron Works, and Magdalen Asylum, showed an average apparent rise at the time of the earthquake of 35 millimeters (1.4 inches) as determined by the Coast and Geodetic Survey leveling. As the leveling simply gives relative elevations the question arises, Does this quantity represent an average rise of the thirteen bench-marks or does it represent a settlement of the zero of the tide-gage and the adjacent bench-marks at the Presidio Wharf? The tidal observations are not competent to determine this question with certainty. The general experience with determinations of mean sea-level, from long series of tidal observations, warrants the statement that the error in determination from a single year is as apt to be greater as less than 0.75 inch (19 millimeters) and that it may sometimes be as great as 2.5 inches (64 millimeters). It is possible, therefore, that the two bench-marks at the Presidio Wharf and the zero of the tide-gage have settled 35 millimeters or that it is, in part, a subsidence at the Presidio and in part a rise at the other places.

The elevations of the group of four bench-marks in the table commencing with 40B at the Appraisers' Building, were determined before the earthquake by the city engineer, but not by Coast and Geodetic Survey leveling. These four, in various parts of the city, show no apparent change in elevation greater than 69 millimeters (2.7 inches). Two of them apparently rose and two subsided.

The apparent changes in elevation of the three bench-marks in the table, commencing with 41 at California and Montgomery Streets, are not supposed to have much significance in connection with the question of whether a general change of elevation took place. These three bench-marks were each subject to local disturbances during the earthquake or were near or on filled ground.

In ten cases the old leveling determined elevations of hydrants and the new leveling determined elevations on hydrants in the same locations but known, from the descriptions, to be different from the old hydrants. Similarly, in seven other cases, the old leveling established the elevations of points on curbstones, steps, or doors, and in each of these cases in the new leveling it was found to be impossible to recover the old point accurately. In all of these 17 cases there is, therefore, only an approximate connection between the old and the new leveling. The evidence from these bench-marks has all been examined carefully and does not lead to any different conclusion from that which may be drawn from the table above.

The general conclusion from both the leveling and the tidal observations is that, within the region examined, there occurred no general change of elevation of sufficient magnitude to be detected with certainty.

It is an opportune time, at present, on account of local changes in elevation at various bench-marks, to adopt the best possible determination of mean sea-level which is available up to date and to refer all new elevations determined since the earthquake to that datum. Accordingly, the reading 8.652 feet (2.7371 meters) on the tide-staff at the Pre-

sidio, given in column 5 on page 143 which is the mean for the three complete years, May 1, 1904, to April 30, 1907, is adopted as being mean sea-level. The values given in column 4 of the table on page 143 are referred to the reading 8.514 feet (2.5951 meters) as mean sea-level. Hence, a correction of − 0.138 foot (− 0.0420 meter) should be applied to these values to obtain the elevations now adopted as best.

It is uncertain, as already indicated in this report, whether this correction of −0.0420 meter is due to improvement in the determination of the relation of mean sea-level to the tide-staff or to a subsidence of the tide-staff and adjacent bench-marks in 1904 or earlier, or to both.

NOTE ON THE COMPARISON OF THE FAULTS IN THE THREE EARTHQUAKES OF MINO-OWARI, FORMOSA, AND CALIFORNIA.

BY F. OMORI.

The three great earthquakes of Mino-Owari (Central Japan) on October 28, 1891, of Kagi (Formosa) on March 17, 1906, and of California on April 18, 1906, were each accompanied by the formation of remarkable geological faults, whose total lengths were about 100, 50, and 430 kilometers respectively. The dislocation in the California earthquake was formed partly along, and partly off, the coast of California, belonging to the category of longitudinal faults.

The dislocation in the Mino-Owari and Kagi earthquakes were, on the other hand, formed nearly at right angles to the course of the Main Island (Nippon) and the axis of Formosa Island respectively, both belonging to the category of transverse faults.

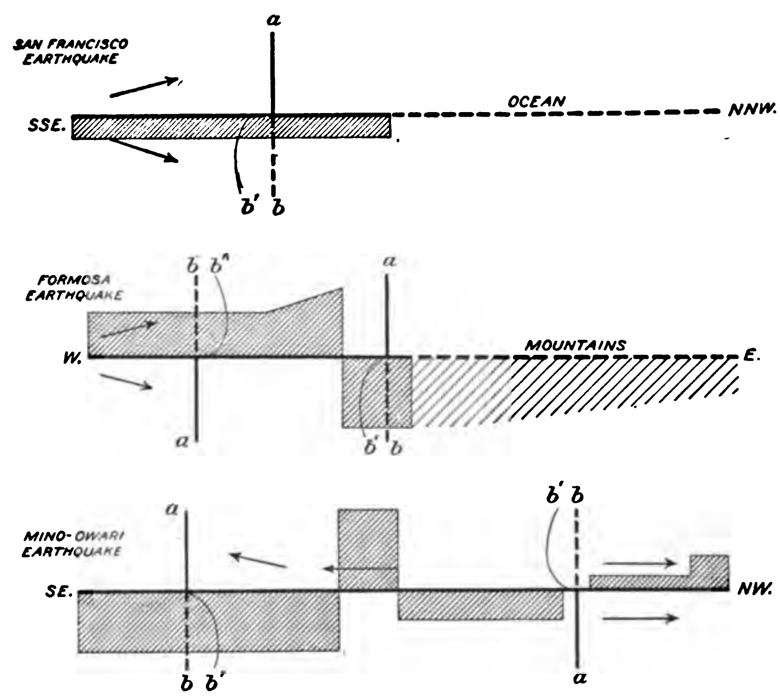


FIG. 43 a. — Full line is fault (ascertained). Shaded part is depressed region. Dotted line is probable continuation of fault. Lightly shaded part represents probable depression. Arrow indicates the direction of maximum (vibratory) motion.

Notwithstanding these differences, there are certain similarities among the three cases. Thus, in each of the three earthquakes, the direction of motion at different places in the immediate neighborhood of the fault was not perpendicular, but more nearly parallel, to the strike of the latter. This seems to indicate that the formation of the faults was mainly due, in each case, not to such actions as a simple falling down or sudden creation of a cavity underground, but to the existence of shearing stresses in the plane of fracture possibly of two opposing forces acting either from the center toward both ends of the fault-line, or toward the center from both ends.

The accompanying figure is a diagrammatic illustration of the three faults, the line *ab* indicating, in each case, a straight line (say, road) which suffered a shearing movement in such a way that the part *b* on the depressed side was displaced to the new position *b'*, and generally transformed into a curve.

From the figure it will be seen that there existed in each fault what may be called the *central point*, where the disturbance of the ground is greatest and about which the shear and depression along the line of dislocation is more or less symmetrical. In the case of the Mino-Owari earthquake the central point was in the vicinity of the village of Midori in the Néo-Valley, where a very remarkable depression of the ground took place. The corresponding point on the Formosa fault was between the villages of Bishō and Kaigenkō. In the California earthquake the northern half of the fault was in part under the ocean, but the central point was probably in the vicinity of the Tomales Bay, the greatest amount of disturbance having occurred there.

The greatest vertical dislocation of 18 feet occurred in the Mino-Owari earthquake, while the greatest horizontal shear occurred in the California earthquake. In the latter the vertical displacement was only 1 or 2 feet, while in the former there was also a large horizontal shear of about 18 feet. In the Formosa earthquake, whose magnitude was much smaller than the other two, the vertical and horizontal displacements of the ground were each of a moderate scale, the maximum amounts being 6 and 8 feet respectively. The maximum (vibratory) motion in the Mino-Owari earthquake showed a tendency of being directed from the central point toward each end; while, in each of the two other earthquakes, the same motion was, as far as can be ascertained, directed from one end toward the center. Again, the direction of the maximum (vibratory) motion was, in the Formosa earthquake, the same as that of the shear of the depressed ground. In the two other earthquakes, however, the reverse was the case. These differences are probably due to the variation in the manner of the action of the force along the fault-plane which finally produced the dislocations.

REVIEW OF SALIENT FEATURES.

The differential displacement of the earth's crust effected by the movement on the San Andreas fault on April 18, 1906, may for convenience be resolved into two components, the horizontal and the vertical. Of these the horizontal movement was the more important and was susceptible of measurement, giving minimum values for the amount of displacement in this direction practically all along the trace of the fault, except at the extreme north and extreme south. The vertical movement was small compared with the horizontal, and was established satisfactorily only in the region to the north of the Golden Gate.

Two kinds of evidence of vertical displacement were available. The first of these was the formation of scarps along the fault-trace, and the second was the change on portions of the coast of the level of the land relatively to sea-level. The scarps that appeared as features of the fault-trace were in part fresh facets where none had existed before the earthquake and in part accentuations or additions to old scarps due to former movements. In both cases exact measurements were rendered difficult by the drag of the soil along the rupture, and by the complication due to the larger horizontal movement. But making all allowances for the masking effect of drag of the soil, it is certain that the height of these scarps, or of the additions to old ones, was quite variable, even in the same general locality, within a range of a few inches up to about 3 feet. It is suggested that this variation is referable in considerable measure to the drag and adjustment of materials in the zone beneath the soil; so that the true displacement of the firm rocks lies between the extremes observed.

The evidence of vertical displacement, based on the recognition of scarps, indicates a slight upward movement of the crustal block on the southwest side of the fault in the northern territory. South of the Golden Gate there is no very satisfactory or consistent

evidence of differential vertical movement. For many segments of the fault-trace in this region, there is no suggestion of displacement of this kind. In other portions, notably in the vicinity of Black Mountain and southward, the movement appears to have been distributed over a considerable zone, with the formation of many auxiliary cracks. Upon the latter scarps were formed, but these in some cases faced the northeast and in others the southwest, and the resultant effect is not known. Judging from the localities where the movement was not so distributed, but was confined to a narrow zone, the differential vertical displacement was nil.

Similarly, the evidence of vertical displacement, based on a comparison of the relative position of land and sea-levels before and after the earthquake, is limited to the region north of the Golden Gate. The Point Reyes Peninsula appears, from this class of evidence, to have been probably upraised slightly by the fault movement; but the evidence is not entirely conclusive.

Observations conducted by the Coast and Geodetic Survey thruout the year succeeding the earthquake, at the tide-gage station near Fort Point in the Golden Gate, show that the relative level of land and sea at that point is the same as it was before the earthquake. Since this station lies on the northeast side of the fault, the observation would appear to indicate that any upward movement of the crustal block on the southwest side was an absolute one.

The horizontal displacement on the fault, as measured on fences, roads, and various structures which crost the fault-trace, is also apparently quite variable, ranging from a foot or less up to 20 or 21 feet. This variation is probably due to a number of causes. The principal one of these is the fact that the displacement was not always confined to the sharp line upon which an offset was observed at any locality. Auxiliary cracks, distributed over a zone not uncommonly a few hundred feet wide, took up portions of the displacement; and these auxiliary cracks doubtless escaped observation in many cases. Indeed, owing to the yielding character of the superficial mantle of soil and regolith, it is probable that many of these auxiliary cracks did not appear as ruptures at the surface. Besides this distribution of the displacement on auxiliary cracks satellitic to the main rupture, the deformation of the ground along the latter, both superficially and in its deeper portions, was probably variable. The extent of this drag is shown in a few instances that have been susceptible of measurement; notably the fence at Fort Ross, surveyed by Mr. E. S. Larsen, on which a displacement of 12 feet was distributed over a distance of 415 feet on the southwest side of the fault-trace; the roadway near Point Reyes Station, where a displacement of 20 or 21 feet was distributed over 60 feet; the fence south of Mussel Rock, surveyed by Mr. H. O. Wood, in which a displacement of 13 feet was distributed over 250 feet on the southwest side of the fault-trace and 40 feet on the northeast side; the 3 fences surveyed by Mr. R. B. Symington near San Andreas Lake, one showing a displacement of 16.9 feet, distributed over more than 1,100 feet, the second a displacement of 10.4 feet distributed over more than 300 feet, and the third a displacement of 12.7 feet distributed over more than 2,200 feet; and the tunnel at Wright, surveyed by the engineers of the Southern Pacific Company, showing a displacement of 5 feet distributed over nearly a mile on the southwest side of the fault-trace. These instances are doubtless indicative of the general character of the deformation of the ground in the immediate vicinity of the fault, and aid in understanding the variable expression of the amount of offset at the main fault-trace. The recognition of the distribution of the movement on auxiliary cracks, some of which may not have appeared at the surface, and the deformation of the ground along the zone of rupture, justifies the conclusion that, except under peculiar conditions — such, for example, as in the marsh at the head of Tomales Bay — the maximum figures obtained for the displacement by the measurement of offsets at the surface must be a minimum expression for the true extent of the

movement in the firm rocks below. For the middle half of the extent of the fault-trace from Point Arena to Crystal Springs Lake, these maximal measurements are very commonly from 15 to 16 feet, and these figures may thus be taken as a minimum expression for the amount of the displacement on the fault for this segment. In the southern quarter of the extent of the fault-trace, the maximum offset is about 8 feet, and this may similarly be taken as a general minimum expression for the displacement on this segment, except for the extreme south end, where it dies out. The amount of displacement at the northern end of the fault has not been ascertained.

The geodetic measurements of the earth movement, as presented in the paper by Messrs. Hayford and Baldwin, are of extreme interest and form one of the most important contributions to the study of the earthquake. The evidence of displacement observed along the fault-trace affords measurements of the total relative movement only, while the geodetic work gives us an approximate measure of the absolute movement on either side of the fault, and the distribution of the movement away from the fault. The results of this geodetic work are not only set forth in detail by the paper of Messrs. Hayford and Baldwin, but they are also admirably summarized, so that all that seems necessary in this place is to discuss very briefly these results from a geological point of view.

A notable feature of the paper is the discovery of a movement of the earth's crust which antedates the earthquake of April 18, 1906, and which is referred to the earthquake of 1868; altho it is recognized that the date and duration of the movement cannot, on the data available, be positively determined. Inasmuch as the time of this movement is left an open question, and is referred to the year 1868 largely as a matter of convenience in discussion, it may be of advantage to inquire briefly whether or not it may have some other significance than that of a sudden movement occurring in that year.

Altho, as shown in another part of this report, the earthquake of 1868 was related to a rupture or series of ruptures of the ground at the base of the hills on the northeast side of San Francisco Bay, there was no evidence of a large relative displacement such as occurred in 1906. It seems reasonable to suppose that if the earlier movement in question had occurred suddenly in the same way as that of April 18, 1906, we should have had a similar manifestation of faulting within the region affected. Since there was no such manifestation the reference of the earlier movement to the earthquake of 1868 may be fairly questioned, and another hypothesis entertained to explain it, particularly if this hypothesis harmonizes in some considerable measure with the results of the geodetic survey.

This hypothesis is that the earlier movement is not immediately or exclusively associated with the earthquake of 1868, but is the expression of the strain in the earth's crust which led to the rupture or slip of 1906 and the consequent earthquake. That rupture presupposes a condition of strain, and it is difficult if not impossible to conceive of such a sudden disruption except as a relief from strain. Such strain involves the idea of slow displacement; and if a series of points had been established in the territory affected at different dates, with reference to some base beyond it, a measure of this slow displacement or creep of the earth's crust might have been obtained.

The strain culminated in a slip on an old rupture plane and may fairly be supposed to have been more or less symmetrically distributed with reference to that plane, so that when relief was effected by slip, the movement involved would be equal in amount on the two sides of the fault.

This hypothesis and its implications appear to fit fairly well with the results of the geodetic resurvey, particularly for that portion of the territory where the earlier movement can be most satisfactorily discriminated from the displacement of 1906. For example in the Tomales Bay region there are ten points, viz.: Bodega Head, Tomales Point, Tomales Bay, Foster, and Point Reyes Hill on the west side of the fault of 1906, and Bodega, Smith, Mershon, Hans, and Hammond on the east, at which the two move-

ments are separated. These stations are found to have moved in a nearly north direction an average amount of 1.56 meters in the interval between "before 1868" (1856–1860) and "after 1868" (1874–1891). Since the values upon which this average is based were arrived at in part by methods of interpolation, there is no great variation from the average at any of the ten stations. The interval within which this northerly movement took place is rather indeterminate, but may be placed doubtfully at 32 years.

Under the hypothesis here presented this movement continued at a probably uniform rate for the next 16 years up to the time of the earthquake of 1906. This would give us a total northerly movement for the interval from 1856–1860 to 1906 of 2.34 meters. Now the northerly component of the combined earlier and 1906 movements, shown in table 3 of Hayford and Baldwin's paper, is on an average 4.95 meters for the five stations west of the fault-line. This includes the sudden movement of 1906 plus the slow creep of 2.34 meters above deduced. The value for the northerly component of the sudden movement of those points in 1906 is thus 4.95 − 2.34, or 2.61 meters. Similarly the southerly component of the combined movements for the five stations to the east of the fault is found to be on the average 0.09 meters. The southerly component of the sudden movement of 1906 was therefore 0.09 + 2.34, or 2.43 meters. The absolute movement on the two sides of the fault on April 18, 1906, was thus nearly the same in amount.

The reference of the earlier movement to a slow creep thus appears to harmonize with and therefore tends to confirm the *a priori* assumption that the absolute movement of 1906 should have been the same on both sides of the fault. Were data available as to the time at which other groups of stations were determined in position, it is probable that a similar result would be reached. We may consider, therefore, that the earlier movement is better explained on the hypothesis of slow creep, continuing up to April 18, 1906, than on the assumption that it occurred at or about the time of the earthquake of 1868. This conclusion applies to the region north of San Francisco Bay. To the south of the Bay the data available are inadequate for a satisfactory separation of the two movements, except in the case of Loma Prieta, and here the earlier movement appears to have been southerly.

Another result of the geodetic resurvey which points to a slow creep of the region under strain precedent to April 18, 1906, is the distribution of the displacement on that date. The measurements of the absolute displacement on the two sides of the fault show that it was notably greater near the fault than at points remote from it. Thus if we imagine a series of points in a straight line transverse to the fault before the earthquake that line was so deformed that the segment to the west of the fault curved northerly and the segment to the east curved southerly in approaching the fault-trace. This deformation can be most readily explained by supposing that the series of points upon the assumed straight line were determined as to position in the first instance upon the surface of a portion of the earth under elastic strain, so that when relief was effected by rupture, the points tended to assume positions relative to one another which they would have had if they had been determined before the advent of the strain.

It may be further pointed out that the conclusion reached by Hayford and Baldwin to the effect that the absolute movement on the west side of the fault was on the average twice as great as the movement on the east side is founded on the assumption of the stability of the base-line Diablo-Mocho. In view of the unknown extent of the earth movement of April 18, 1906, it would seem preferable to make the assumption that the relief from strain was approximately distributed equally on the two sides of the fault and from this infer the amount of the southeasterly displacement of Diablo and Mocho. The assumption that Diablo and Mocho were not affected by the disturbance of April 18, 1906, is based on the following considerations:

1. There was no change in the azimuth of the Diablo-Mocho line.
2. There was no change in the length of that line.
3. There was no appreciable change in the relations of these two stations to certain others nearer the fault.
4. The latitude of Ukiah remains the same as before the earthquake.

The first three of these conditions would be fulfilled if the region including all the stations occupied had moved in unison southeasterly with but little or no rotation, a possibility which it is difficult to deny. The fourth consideration does not preclude this possibility since the amount of movement involved is probably less than the errors of the method used for the determination of the latitude of Ukiah.

In the region about Monterey Bay the most interesting fact brought out by the geodetic resurvey is that the combined effect of the earlier movement and that of 1906 is a southerly migration of the earth's crust on both sides of the San Andreas rift. It is probable from direct observations of relative displacement along the fault-trace in 1906 that the southwesterly block moved northwest as far as the rupture extended. If this be accepted, then the southerly net movement on the west side of the south end of the fault is due to the predominance of an earlier southerly movement. This agrees with the positive and certain earlier displacement of Loma Prieta. Accepting the southerly character of this earlier movement as certain, there is forced upon us the remarkable fact that the direction of displacement in the region about Monterey Bay is the reverse of that of the earlier movement for the region north of San Francisco Bay. This means that the earlier movement was distensive in character, displacing the territory to the north of San Francisco Bay northerly, and that to the south southerly while the vicinity of the Bay itself was relatively neutral. It appears, moreover, that the southerly displacement was differentially diffused, since the amount of displacement of the south side of Monterey Bay was notably greater than that of the north side, resulting in a widening of the Bay by about 10 feet.

Similarly the distance between Tamalpais and Black Mountain, both on the same side of the San Andreas rift, has been increased by a like amount. The significance of this general distension involved in the reversal of the direction of displacement to the north and south of San Francisco Bay, and of the differential character of this distension, without known rupture, at Monterey Bay and San Francisco Bay, can not at present be stated. The problem requires prolonged study and repeated measurements to secure the necessary data for a proper discussion. It is evident, however, that we are here confronted with some of the most interesting phenomena in the mechanics of the earth's crust, phenomena which call for deliberate investigation extending through years and decades and conducted on a wisely planned program.

PROVISION FOR MEASUREMENT OF FUTURE MOVEMENTS ON SAN ANDREAS FAULT.

The extent of the movement on the San Andreas fault on April 18, 1906, was measured imperfectly and inexactly by offsets of fences, lines of trees, roads, pipes, dams, creeks, shore lines, etc. The distribution of the displacement in the immediate vicinity of the fault, the drag and compression of the soil, the uncertainty as to the former orientation of the lines offset, and other adverse conditions rendered the determinations unsatisfactory to a certain degree. With one exception, the measurements obtained in this way are suspccted of being less than the true amount of relative displacement of the firm rocks below the surface materials.

With the object of obtaining a more exact measurement of any future movements that may take place on the same fault, the Commission caused to be established two sets of piers or monuments in the Rift, in proximity to the fault-trace, upon which instrumental observations could be obtained as to the amount of displacement. This was not done in anticipation of the recurrence of a large movement in the near future, but because it was suspected that there might be slight movements at the times of minor earthquakes, such as are fairly common. Such slight movements might, in the course of years, accumulate to an important amount, and yet the individual increments of the displacement escape notice unless refined methods of measurement are resorted to. It is hoped that the establishment of the monuments and the redetermination of their relative positions from time to time will enable future observers to ascertain whether or not there is a small progressive movement on the San Andreas fault, in addition to the larger movements which cause more violent earthquakes, such as those of 1857 and 1906. Besides serving this purpose, the movements will also be useful in any effort that may be necessary in future to determine with precision the amount of a large displacement.

The localities selected for the position of the two sets of monuments are Olema, Marin County, and Crystal Springs Lake, San Mateo County. These localities are about 40 miles apart on the Rift, and the fault-trace at both was confined to a very narrow zone in 1906, thus permitting the piers to be more closely grouped than at many other localities which for other reasons might have been chosen.

Each set of monuments consists of four concrete piers, established two on each side of the fault-trace of 1906. They are sunk in the ground to a depth of about 6 feet, and are founded either upon rock or upon a firm "hard-pan" arising from the decomposition of the underlying rocks. They rise from 2 to 3 feet above the surrounding surface. The establishment of the piers at Olema was intrusted to Mr. A. J. Champreux, of the Astronomical Department of the University of California, and those at Crystal Springs Lake were set in place by the officers of the Spring Valley Water Company, under the direction of its chief engineer, Mr. Hermann Schussler, who very kindly relieved the Commission of any expense connected with the operation. The piers at Olema are 13 inches square in cross-section, while those at Crystal Springs Lake are 18 inches square. To the summit of each of the piers is fixed a thick bronze plate 13 inches square, with suitable appliances for receiving a selected instrument in a constant position for successive measurements, and a device for determining a fixed point to which to measure. This plate is protected by a heavy iron cap, 14.5 × 14.5 inches, lockt upon it, bearing the inscription:

S.E.I.C.
To measure
earth movements
1906.

The instrument selected for the first and subsequent measurements is a 10-inch altazimuth, the property of the University of California, and the key of the protecting caps is at present in the safe keeping of the same institution.

In order to render the monuments thus established available for future measurements of displacement, it was necessary to have their present relative positions established with precision. This work was very kindly undertaken for the Commission by Mr. B. A. Baird, Assistant, Coast and Geodetic Survey, a report from whom follows, setting forth his methods and results:

RELATIVE POSITIONS OF THE MONUMENTS.

BY B. A. BAIRD.

OLEMA.

Description of monuments. — The monuments at Olema are on Mr. Skinner's ranch, just a little north of the dwelling-house. The two piers west of the fault-trace are in an orchard on level ground, but the other two, which are just east of the road, are on a hill-side, the northeast monument being about 15 feet higher than any of the others. In order to measure and observe between the northwest monument and the southeast monument, a trench about 3 feet deep had to be dug thru the embankments on both sides of the road and somewhat into the traveled portion as well. Some clearing of brush was necessary in order to make the northeast monument and the southwest monument intervisible.

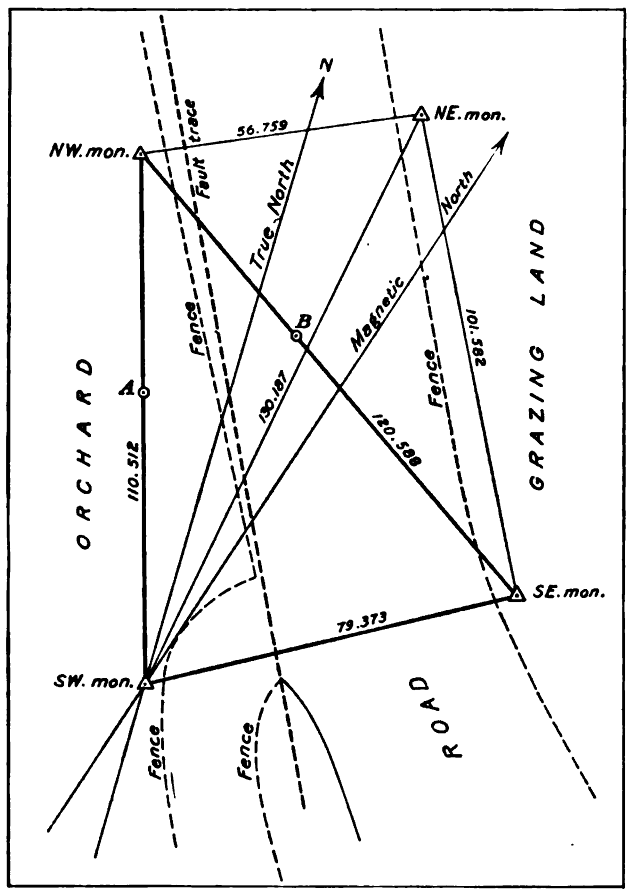
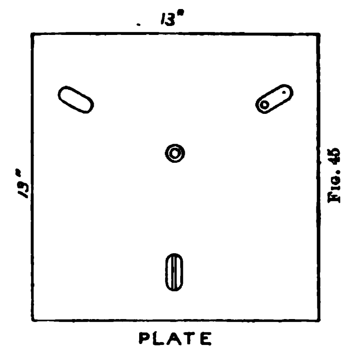


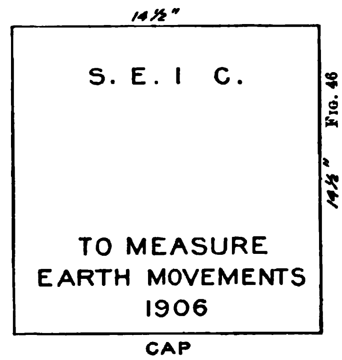
FIG. 44. — Monuments at Olema.

The relative positions of the four monuments are shown in the diagram, fig. 44. The lengths of the three heavy lines were determined by measurement. The measurements of the other three lines were considered impracticable, on account of the great height of the northeast monument above the others, as compared with the short distances between them and it. By means of the three measured lines, however, a double determination is obtained, thru the observed angles, of each of the three lines not measured by the steel tape.

The lines were cleared sufficiently so that all four of the monuments could be occupied with a theodolite, and then all of the lines were observed, including the diagonals. In order that future movements may be readily detected by means of observed angles, the centering of the instrument was considered to be of the greatest importance, especially for such very short lines as these. A bronze plate had been constructed and set up on each monument, especially designed for supporting in position the Fauth 10-inch alt-azimuth instrument of the Civil Engineering Department of the University of California.

A sketch of the plate is shown in fig. 45. The spindle which screws into the central socket of the plate is shown in fig. 47, and the iron cap which protects the plate when the spindle is removed is shown in fig. 46. Referring to the sketch of the plate, it will be seen that there are three lugs, or foot-plates, standing upon and attached to it. In one is a groove (vertex of angle at bottom), and in one a hole (inverted cone), while the third has simply a smooth surface. This arrangement prevents any binding of the foot-screws of the instrument, and insures that it will always be set in the same position in successive measurements.





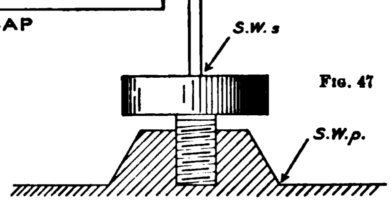


Fig. 45. — Diagram of bronze plate on monuments.
Fig. 46. — Diagram of iron caps protecting plates.
Fig. 47. — Diagram of spindles to be attached to plates.

To doubly insure this, one of the lugs is marked to correspond with a particular support of the theodolite, the corresponding support being similarly marked. This arrangement further insures that even tho the center of the instrument does not correspond exactly with that of the point observed upon (for each monument), thus preventing a closing of the triangles within the accuracy of observation (that is, that the sum of the 3 angles of each triangle should equal 180°), the angles obtained will still correspond with each other in successive observations within the limit of observational errors.

For observing upon, and also for reference points in the base measurements, a spindle has been constructed for each plate. This spindle screws into a cup-like projection fastened upon the plate for a center-mark. Each spindle is numbered to correspond with a particular monument, the corresponding number being upon the plate.

Up to a distance of about 200 feet these spindles make excellent objects to observe upon, provided there is a suitable background. A background that can not be surpast is readily made by propping up behind the spindle the black iron cap which covers and protects the plate when not in use. When the distances are greater than about 200 feet, as is the case with the longer lines at Crystal Springs, the best object to observe upon can be made by whittling the end of a lead pencil to fit into the cup and then wrapping the pencil with a little white cloth. In this case the background should be the same as before. In any event, if tape measurements are contemplated, the spindles should be taken along, in order that they may be used as reference marks in those measurements.

Leveling record. — In the following tabulation, *S. W. p* means the top of the bronze plate on the southwest monument, alongside the spindle bowl or cup near the center. A corresponding point was taken on each monument to show the relative elevations to be retained for future reference.

S. W. s is the top surface of the spindle hub, screwed into the socket, made for marking the center on the same plate. These points were taken to show differences of elevation of points used in the tape measures in the base-lines, and are of no value beyond this.

In computing the elevations, the top of the southwest monument was arbitrarily taken as 10 feet, and the other elevations are corrected to correspond with this datum plane.

The spindle bowl is not in the center of the plate, owing to the position of the lugs, so that the point leveled upon representing the level of the plate is on the side of the spindle bowl next to the center of the plate.

The level used was a Troughton and Simms dumpy level with compass attachment.

[Elevations in feet. — Mean results.]

	First Measures.	Second Measures.	Mean.	Base-Line Elevations.	Differences of Elevation.
S.W. p	10.000	10.000*	10.000	......	....
S.W. s	10.075	10.076	10.076	10.076	....
Stake A	7.465	7.462	7.464	7.464	– 2.612
N.W. p	8.006	8.004	8.005	......	....
N.W. s	8.057	8.053	8.055	8.055	+ 0.591
Stake B	11.694	11.690	11.692	11.692	+ 3.637
S.E. p	11.389	11.390	11.390	......	....
S.E. s	11.455	11.456	11.456	11.456	– 0.236
N.E. p	25.877	25.877	25.877	......	....
S.W. s	......	......	......	10.076	– 1.380

The relative elevations of the four monuments, taking the center of the plate in each case, are as follows:

	FEET.
Southwest monument . . . . (assumed)	10.000
Northwest monument	8.005
Northeast monument	25.877
Southeast monument	11.390

Base-line measures. — B. A. Baird in charge, reading rear end of tape and recording. R. S. Badger, forward end of tape and reading thermometer. Charles Evans (laborer), steadying spring balance attached to end of tape and watching tension of 10.5 lbs. The tape used, a 100-foot steel tape, G. M. Eddy and Co., Catalogue No. 703; was stamped on reel "No. 1" for identification in future use. Its width is 0.272 inch; its thickness 0.010 inch; and its weight per foot 3.8324 grams or 0.00845 lb. This tape, on May 1, was compared with the standard tape at the University of California, a long level stretch on the "bleachers" being used for the purpose. The standard tension of 10.5 lbs. was adopted, and no difference in the lengths of the tapes could be detected.

The standard tape, N.B.S. No. 8, is marked only at zero and 100 feet. The comparisons were made between these marks, and the equality of zero to 50 feet and 50 to 100 feet was measured on the tape used in the base-measures, there being no measurable difference.

The constants of the standard tape, N.B.S. No. 8, are: Temperature of observation, 64.6° F.; Tape supported thruout entire length; tension, 10.5 lbs. avoirdupois; resulting values of spaces at 62° F., assuming coefficient of expansion = 0.0000063 per degree F. are zero to 100 feet = 100 feet 0.00 inch.

FORMULÆ AND CONSTANTS USED IN BASE-LINE COMPUTATIONS.

Correction for Level $= -\frac{h^2}{2d} - \left(\frac{h^2}{2d}\right)^2 \frac{1}{2d}$, where

h = difference of elevation of ends of tape.
d = distance between supports.

Correction for Temperature $= -l\,(T-t)e$, where

l = length of line corrected for.
T = standard temperature = 62° F.
t = mean temperature of tape.
e = coefficient of expansion = 0.0000063 per degree F.

Correction for Sag $= -\frac{l}{24} \cdot \left(\frac{wd}{P}\right)^2$, where

w = weight of tape per foot = 0.00845 lb. per foot.
P = standard tension of 10.5 lbs., the same as used in measures.
d and l same as above.

From the above, $\frac{1}{24}\left(\frac{w}{P}\right)^2 = \frac{1}{24} \cdot \left(\frac{0.00845}{10.5}\right)^2 = 0.00000002700.$

The correction for *pull*, accounting for elasticity of tape, is not necessary, since the standard tension was used in the measures.

Level correction. — In taking the measurements, the center of the spindle, firmly screwed into the cup on the bronze plate, as shown in the diagram, fig. 47, was the reference mark on the monuments.

The ordinary correction for level, $\frac{h^2}{2d}$, is not sufficiently accurate when the differences are large, and a second correction has been allowed for. In the corrections at Crystal Springs, even third approximations are necessary.

The computed values of the measured lines are summarized as follows:

[Computed lengths of bases (feet).]

	FORWARD.	BACKWARD.	MEAN.
N.W. to S.W. Mon.	110.1528	110.5115	110.512
N.W. to S.E. Mon.	120.5890	120.5878	120.588
S.E. to S.W. Mon.	79.3728	79.3725	79.373

CRYSTAL SPRINGS LAKE.

Description of stations. — These monuments are about 7 miles northwest of San Mateo on the eastern shore of Crystal Springs Lake, the reservoir of the Spring Valley Water Company. The location is about a mile southeast of Camp Sawyer, which is on the west side of the lake at a point where the lake is very narrow and is spanned by a bridge, close to the northern end.

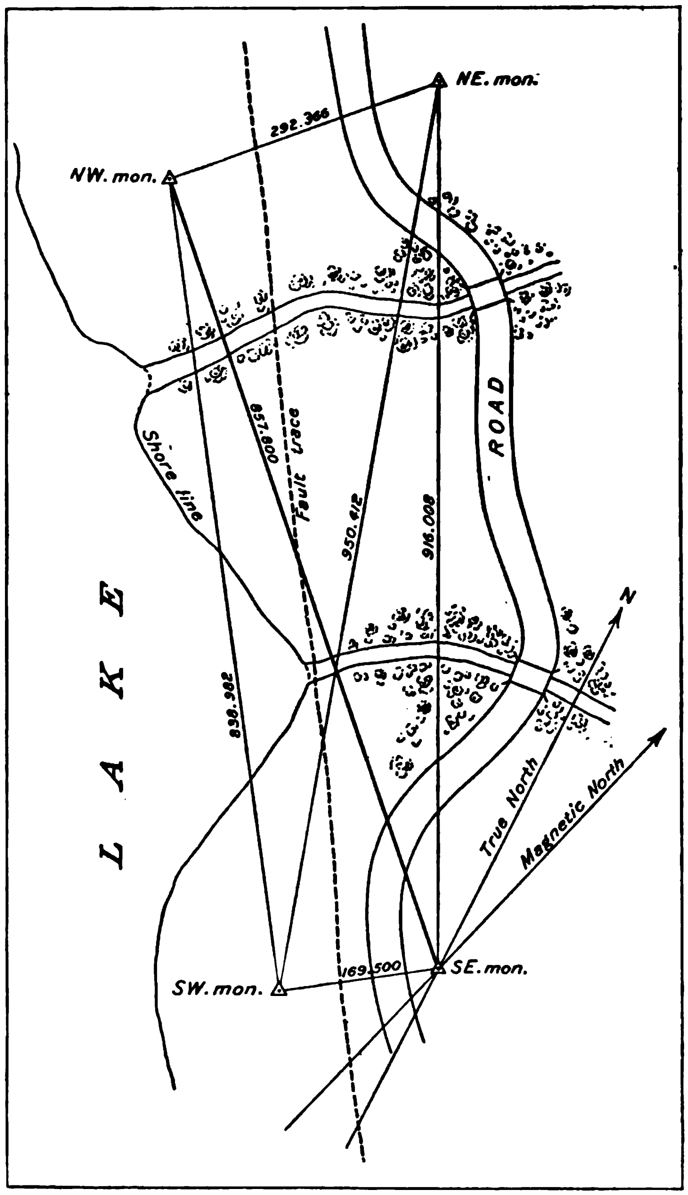


Fig. 48. — Monuments at Crystal Springs Lake.

As will be seen from the leveling record, and from the accompanying rough sketch, fig. 48, the ground is very uneven, and the measurement of a base-line was executed under considerable difficulty. The line measured, which was the only practicable one, crosses two ravines and comes up toward the southeast monument, over a very steep road embankment. Considerable clearing of brush was necessary in order to cross the ravine near the northwest monument. On account of the large differences of level between the base-line stakes in some places, the leveling had to be done with extreme care, there being at one place a rise of 11.5 feet in 50 feet, and, next to the road embankment, a rise of about 6 feet in 20 feet.

The plates, spindles, and caps are the same as those described under "Description of Monuments" at Olema. The distances between these stations being too great to observe upon the spindles with advantage, pencils were wrapt with white cloth and set in the spindle cups upon the plates, the bronze protecting caps being used for background, as in the Olema measurements.

Base-line measures. — The stakes, made long enough to stand above the grass, were lined in with the alt-azimuth instrument, and to avoid the possibility of errors they were all numbered on top with a blue crayon. The stakes were made of redwood, and the method of marking was to stick a pin straight down in the top of each at the marking edge of the tape. The tape used was marked to hundredths of feet the entire length, the thousandths being estimated. The measurements were so taken as to avoid estimating the thousandths, excepting on the last measure, the mark being arbitrarily placed at the nearest convenient tenth of a foot on the top of each forward stake.

As the diameter of the pins used was almost exactly the same as the width of the 0.1-foot marks on the tape, the marking could be done with exceptional accuracy, especially by holding the eye directly over the mark in such a way that there would be no parallax. The spring balance was fastened to the forward end of the tape, and steadied by means of a cord looped so as to slip up and down on a pole, held by a man who at the same time watched the tension. To avoid any pulling against the stakes, the height of the tape was regulated by means of the loop so as just to graze the top of the stake. All the marking was done at the forward end of the tape, the officer in charge at the rear end simply steadying on the mark of the previous measure and then reading the tape.

The lengths of the base joining the southeast and northwest monument resulting from the measurements are the following:

	Feet.
First measure	857.8020
Second measure	857.7988
Mean	857.800

Relative elevations. — By means of precise leveling the relative elevations of the four fixed monuments, taking the center of the top of the bronze plate in each case, were found to be as follows:

	Feet.
Northwest monument	(assumed) 50.000
Northeast monument	86.513
Southeast monument	75.787
Southwest monument	46.113

Method of observing angles. — The instrument used was a 10-inch alt-azimuth theodolite, carrying two micrometers 180° apart. Each micrometer head is divided to represent seconds of arc, enabling the observer to estimate to tenths of seconds of arc at each reading. In taking the observations, each micrometer was read to correspond with two consecutive 5-minute divisions, one being back of the reference mark and one in front. The corrections for "run" at each station were based upon the observations themselves, the mean of all observations at the first two monuments being taken both at Olema and at Crystal Springs. In order to eliminate all possible instrumental errors, the observations were, in general, taken in four sets, having for the initial reading of each set, 0°, 90°, 45°, and 135°, respectively; making for the reversal of the telescope, without changing the setting of the circle, the corresponding readings of 180°, 270°, 225°, and 315°.

Thus, upon each station there were eight pointings of the instrument, representing eight portions of the circle equally divided. Since for each of these pointings there are two micrometers, each giving two readings of the thread, there were in reality 32 micrometer readings for each observed station. The above statements apply fully at Crystal Springs, but at Olema one micrometer was not in condition to use, so that the Olema observations, while constituting the same number of telescope pointings, represent for each observed station but 16 micrometer readings.

At Olema, on account of the very small distances between the monuments, large changes of focus were necessary for the different pointings. This, combined with the large differences of elevation, and lack of perfect centering of the instrument on the plates to correspond with the positions of the spindles, prevented the triangles from closing to a very high degree of accuracy. Still, when these discrepancies are reduced to errors of distance, they become practically inappreciable.

At Crystal Springs, where the lines are much longer, the closing of the triangles was very good. The correction for each angle, in order to make the sum of the angles of each triangle equal to 180°, was on the average only about one second of arc. This goes to indicate that this instrument, when properly used, is capable of excellent results. At Crystal Springs a least square reduction of the observations has been made, but the angles and distances thus computed are almost identical with those of the original computation.

At Olema, where the three lines having the least differences of level were measured, the diagonal between the northwest monument and the southeast monument (being best suited for computation) was taken as a base for computing the other two measured sides. The means of the computed and measured distances of these two sides, together with the direct measure of the above-mentioned diagonal, were taken as the best measures for computing the unmeasured sides. The lengths of the three unmeasured sides, therefore, depend not only upon the observed angles, but upon the lengths of the three bases, as indicated above. This method gives the measured distances and observed angles about equal weight, the angles being corrected for each triangle according to what is known as the "field adjustment." As above noted, however, it is very doubtful if the angles are entitled to as much weight as the measured distances, and hence, it was decided to retain the exact values of the three measured distances, and make a "least square" adjustment of the angles of the quadrilateral to correspond.

The three measured sides being assumed as fixed, the three angles of the triangle N.W. Mon., S.E. Mon., S.W. Mon., can each have but one value, and these values have been computed from the three sides. These three sides and the corresponding angles remaining fixed, an adjustment is made between the remaining angles and the three unmeasured sides, so as to fulfill all the geometrical conditions, giving at the same time the most probable values, according to the theory of "least squares."

Abstracts of horizontal angles. — In the abstracts of horizontal angles tabulated below, the first set of angles given under the heading "Observed" are the means of angles taken directly from the original records. The column headed "Field Adjustment" shows the angles as they appear in the field computations after the angles of each triangle have been corrected to sum up 180°, giving the same correction to each angle in a particular triangle. This adjustment, which is the usual one made in the original computations, does not account for the other geometrical conditions required for the rigid solution of a quadrilateral, but when the errors in the angles are small, the resultant distances, especially if short, will be very near the truth. The column headed "Least Square Adjustment" shows the angles computed so as to fulfill all the geometrical conditions, giving their most probable values according to the theory of "least squares."

In future measurements, it will not be necessary to repeat the base-measurements unless the angles show some change, for by occupying all the stations, any change that could be detected by tape measurement will at once show in the angles. When, however, the angles indicate any change, then a remeasurement of at least one line will be necessary.

[Abstract of Horizontal Angles. — Olema. Mean of eight pointings on each station.]

	Observed.			Field Adjustment.	Least Square Adjustment.		
At N.E. Monument:							
S.E. Mon. to S. W. Mon.	37°	33′	23.6″	24.6″	37°	33′	26.7″
S.W. Mon. to N.W. Mon.	57	24	50.4	61.8	57	25	21.6
S.E. Mon. to N.W. Mon.	94	58	14.0	22.1	94	58	48.3
At S.E. Monument:							
S.W. Mon. to N.W. Mon.	63	12	13.4	17.6	63	12	29.7
N.W. Mon. to N.E. Mon.	27	57	59.1	67.2	27	57	48.6
S.W. Mon. to N.E. Mon.	91	10	12.5	13.5	91	10	18.3
At S.W. Monument:							
N.W. Mon. to N.E. Mon.	25	38	40.6	52.0	25	38	41.9
N.E. Mon. to S.E. Mon.	51	16	20.9	21.9	51	16	15.0
N.W. Mon. to S.E. Mon.	76	55	01.5	05.8	67	54	56.9
At N.W. Monument:							
N.E. Mon. to S.E. Mon.	57	03	22.6	30.7	57	03	23.1
S.E. Mon. to S.W. Mon.	39	52	32.3	36.6	39	52	33.4
N.E. Mon. to S.W. Mon.	96	55	54.9	66.2	96	55	56.5

[Distances in feet.]

	Measured.	Computed.	Mean.	Least Square Adjustment.
S.E. Mon. to N.W. Mon.	120.588	....	120.588	120.588
S.E. Mon. to S.W. Mon.	79.373	79.373	79.373	79.373
S.W. Mon. to N.W. Mon.	110.512	110.508	110.510	110.512
N.E. Mon. to N.W. Mon.	....	56.768	56.768	56.759
N.E. Mon. to S.W. Mon.	....	130.191	130.191	130.187
N.E. Mon. to S.E. Mon.	....	101.584	101.584	101.582

[Abstract of Horizontal Angles, Crystal Springs Lake. Mean of eight pointings on each station.]

	Observed.			Field Adjustment.	Least Square Adjustment.		
At N.W. Monument:							
N.E. Mon. to S.E. Mon.	92	01′	49.2″	49.5″	92°	01′	49.9″
S.E. Mon. to S.W. Mon.	11	23	43.5	43.5	11	23	44.9
N.E. Mon. to S.W. Mon.	103	25	32.7	34.8	103	25	34.8
At N.E. Monument:							
S.E. Mon. to S.W. Mon.	10	12	21.8	20.1	10	12	19.0
S.W. Mon. to N.W. Mon.	59	09	45.1	47.2	59	09	47.9
S.E. Mon. to N.W. Mon.	69	22	06.9	07.3	69	22	06.9
At S.E. Monument:							
S.W. Mon. to N.W. Mon.	77	57	38.1	38.1	77	57	37.0
N.W. Mon. to N.E. Mon.	18	36	02.8	03.2	18	36	03.2
S.W. Mon. to N.E. Mon.	96	33	40.9	39.2	96	33	40.2
At S.W. Monument:							
N.W. Mon. to N.E. Mon.	17	24	35.9	38.0	17	24	37.3
N.E. Mon. to S.E. Mon.	73	14	02.4	00.7	73	14	00.8
N.W. Mon. to S.E. Mon.	90	38	38.3	38.4	90	38	38.1

[Distances in feet.]

	Measured.	Field Computation (Base-Line).	Least Square Adjustment.
S.E. Mon. to N.W. Mon.	857.800	....	857.800
N.E. Mon. to S.W. Mon.	....	950.414	950.412
N.E. Mon. to N.W. Mon.	....	292.368	292.366
N.E. Mon. to S.E. Mon.	....	916.008	916.008
S.W. Mon. to S.E. Mon.	....	169.500	169.500
S.W. Mon. to N.W. Mon.	....	838.984	838.982

ISOSEISMALS: DISTRIBUTION OF APPARENT INTENSITY.

INTRODUCTORY.

In the study of earthquakes the distribution of the intensity of the shock over the region affected is usually an important part of the investigation. The intensity is inferred, as a rule, from the records of instruments established for the purpose, and from the effect upon persons, loose objects, and structures. In the region affected April 18, 1906, however, seismograph instruments were very few, and the distribution of the intensity of the shock has been determined largely by the effects noted. These effects are graded in various convenient scales and the gradation of intensity is indicated upon maps in the form of lines or curves, known as isoseismal curves, which express, as well as the data available will permit, zones or belts of equal intensity more or less concentric to the point or line above the seat of disturbance. The purpose of plotting such isoseismal curves is to locate approximately that portion of the earth's surface immediately above the seat of the disturbance. In a discussion of the ideal case, the latter is supposed to be a point or *centrum*, and the place above it at the surface is called the *epicentrum*. The increase in our knowledge of earthquakes in recent years has, however, made it clear that the seat of disturbance is rarely if ever a point, but is usually distributed over a plane of rupture in the earth's crust. When this plane of rupture is of small extent, as frequently happens, the terminology is little affected by the use of the expressions *centrum* and *epicentrum* in the discussion of the phenomena; but where, as in the larger earthquakes, the plane upon which movement in the earth's crust takes place has a great horizontal extent, then these terms become misnomers and tend to obscure the facts. In the present case the inappropriateness of the terms *centrum* and *epicentrum* is glaringly apparent and they will, therefore, be avoided in this discussion.

In the case of the California earthquake, the plotting of isoseismal curves for the purpose of discovering the region on the surface above the seat of the disturbance is in a large measure obviated by the fact that the rupture in the earth's crust is revealed at the surface in the form of a fault traceable practically continuously for 190 miles, and probably continuously for 270 miles. This fault is undoubtedly the principal seat of the movement which caused the earthquake. Notwithstanding this fact, the study of the distribution of intensity is a matter of importance. It is highly desirable, where the plane of rupture is open to the surface and its trace is definitely ascertained, to plot the isoseismal curves, since their disposition under these circumstances may illuminate the general method of determining the position of a deep-seated fault which causes an earthquake, but is not apparent at the surface. It may at least contribute to a definition of the limitations of the method.

It is, moreover, desirable that the distribution of the intensity of the shock should be determined as accurately as possible, since we can not safely assume that the main fault, which appears as a rupture of the earth's crust from San Benito County to Humboldt County, is the only one which occurred on the morning of April 18. Indeed there are *a priori* grounds for believing that more than one dislocation of the earth's crust occurred at the time of this great disturbance of the equilibrium of the stresses within it. If, in a region where stresses have accumulated to nearly the snapping point, a rupture is suddenly effected in one place, it seems probable that the jar thus generated might precipitate ruptures in neighboring parts of the region under similarly high stresses. It appears, therefore, to be highly desirable to plot the gradations of intensity for the region affected; not to discover the trace of the main fault, which is well known, but to see if such gradations indicate auxiliary faults in neighboring territory which did not appear as ruptures

at the surface. In attempting this task, certain conditions which militate against the accuracy of the results and others which affect their interpretation should be stated.

In the first place, the scale upon which the gradation of intensity is indicated, that known as the Rossi-Forel scale, is more or less arbitrary. At the outset of the inquiry, the Commission revised and simplified this scale somewhat, with the object of adapting it for general use, and its present form, as amended by the Commission, is as follows:

I. *Perceptible*, only by delicate instruments.
II. *Very slight*, shocks noticed by few persons at rest.
III. *Slight shock*, of which duration and direction were noted by a number of persons.
IV. *Moderate shock*, reported by persons in motion; shaking of movable objects; cracking of ceilings.
V. *Smart shock*, generally felt; furniture shaken; some clocks stopt; some sleepers awakened.
VI. *Severe shock*, general awakening of sleepers; stopping of clocks; some window glass broken.
VII. *Violent shock*, overturning of loose objects; falling of plaster; striking of church bells; some chimneys fall.
VIII. Fall of chimneys; cracks in the walls of buildings.
IX. Partial or total destruction of some buildings.
X. Great disasters; overturning of rocks; fissures in surface of earth; mountain slides.

It is apparent that the scale leaves room for wide variation in the personal equation. Different reporters interpret the same experiences and the same phenomena differently. It was also found that in the periphery of the region affected, where the earth waves were of slow period, pendent objects and liquids were more sensitive indicators of earth movement than direct perception by individuals, altho the latter is placed first in the scale. Prof. G. D. Louderback, who reported upon the intensity of the shock in the region east of the Sierra Nevada, makes the following pertinent comment upon this point:

In the towns along the east base of the Sierra Nevada and within 25 or 30 miles of the base, the shock was distinctly felt, movable objects were seen to swing and heard to bump or rattle, and a very small number of persons were awakened. Farther east the most notable feature of the reports is that wherever the effects of the earthquake were made evident, the physical signs, such as the swinging of suspended objects, etc., were described almost to the exclusion of direct physiological effects. This is apparently at variance with the principle upon which the Rossi-Forel scale is founded, as the first three grades of intensity are based on feeling, the visible disturbance of objects not beginning till grade IV is reached. Perhaps the most important physical sign reported is the disturbance of smooth water surfaces. In five instances, at three different localities, ditch tenders or irrigators noticed an agitation of quiet water surfaces, and that water lightly splashed against the sides, as if from low waves, or as in a vessel of water when it is slightly tilted. As the morning was clear and entirely without wind, it imprest them as peculiar, and the matter was reported when they went to breakfast. The suggestion of one that something peculiar had happened, and of another that it was an earthquake, was each in its place the incitement of sallies of wit at the expense of the reporter. News of the California earthquake reached these places several hours afterwards and the time was then found to agree as closely as determinable with the phenomena of the morning. In each of the cases, however, it was reported that no shock was felt. It is suggested that with moderately long waves such surfaces might prove very sensitive indicators of intensities down to the lowest degree on the scale.

The movement of liquids in vessels, ponds, lakes, or streams, is not included in the scale, altho numerous reports were made of such movement and estimates as to the intensity of the shock were based thereon. The stoppage of clocks appears to be a very uncertain criterion of intensity. In the 6th, 7th, 8th, and 9th degrees of the scale, wherein damage to buildings is relied upon for an estimate of the intensity, two important factors tend to vitiate the conclusions arrived at as to the comparative intensity. These are (1) the great variability of the character of the structures and (2) the character of the ground upon which they are built. The scale was probably designed originally for regions where brick and masonry structures prevail, while in California wooden structures are by far

the most common. The latter, by reason of their greater elasticity, are usually much better adapted to withstand the wracking movement of an earthquake shock than are brick and masonry walls. The intensity, as inferred from a region of wooden buildings, would, therefore, in general appear to be less than that for a region of brick or masonry structures. Even among the latter, and among the brick chimneys of wooden houses, which were so generally used as indicators of intensity, there is great variation in strength due to the variation chiefly in the character of the mortar used in their construction.

Along river bottoms and on valley floors, particularly where the ground water is abundant, structures were much more susceptible to damage than similar structures founded on the firm rocks of the valley slopes. This apparently high intensity of the shock in the valley lands was in part due to an actual slumping of the ground, which wracked the buildings independently of any elastic vibration communicated to them from the ground.

Finally, in grade X of the scale, fissures in the ground are taken as a criterion of the highest grade of intensity, when in reality such fissures have under different conditions very different values from this point of view. The fissures which extend down into the earth's crust, and are due to its actual rupture on a fault-plane, are of course significant of the highest degree of disturbance usually experienced in earthquakes; but those cracks and fissures which occur in valley bottoms, due to the slumping of soft material toward the stream trench, or those cracks which are associated with landslides, in those cases where the landslide was imminent and was merely precipitated by the earth jar, are superficial phenomena and do not necessarily indicate so high a degree of intensity as that marked X on the scale. It therefore becomes necessary to discriminate such fissures, and this was not always done in the reports sent in to the Commission.

These various imperfections in the scale used for grading the intensities would of course be minimized if the entire field were examined and reported upon by one observer. The personal equation would in that case, for practical purposes, be constant. But when the observations were made over so vast a field by a great number of persons, so diversely qualified for the work, the errors are necessarily numerous.

Added to this are the large gaps in the records, due to the scant population in the more mountainous parts of the region affected. In these thinly populated tracts, there is not only an absence of individual observations at the time of the earthquake, but also a lack of structures which would reveal to subsequent examination the effects of the shock.

It will thus be apparent that any effort to map the distribution of the intensity of the earthquake can only yield rough approximations to the actual facts. Yet such approximations have their value, and the Commission has not been discouraged by the imperfections of the method from applying it to the full extent permissible under the circumstances. The results are given graphically on the isoseismal map which accompanies this report. (Map No. 23.)

In compiling this map, it has been found best to plot the intensities upon the basis of a literal interpretation of the Rossi-Forel scale, as regards damage to structures. It results from this that in the river bottom the curves represent zones of equal destructive effects, but not necessarily zones of equal intensity, interpreted in terms of acceleration of the vibratory movement of the earth. In these tracts we are confronted with the question as to whether the locally high destructive effects were wholly due to the character of the ground, as in part they certainly were, or whether these may not be ascribed in part to local auxiliary faults in the earth's crust which did not appear as ruptures at the surface. This question will receive special consideration in the sequel, when the facts have been more fully set forth.

It is now proposed to describe somewhat in detail the effects of the earthquake which serve as the basis of the isoseismal map, beginning at the north and going southerly.

SOUTHERN OREGON.

The most northerly point on the coast for which we have a record of the earthquake shock having been felt on the morning of April 18 was at Coquille, Oregon. Here Mr. E. S. Larsen reports that Judge Harlocker was awakened by the shock at about 5 o'clock. Mr. Wilson and his wife were awakened and noticed the cord of an electric lamp swinging east and west. The regulator in Mr. Wilson's jewelry store, facing east, stopt. Others were awakened. Mr. Larsen also reports that the shock was felt at Bandon, and that at Kerby some claim to have felt it.

At Williams some sleepers were awakened. At Glendale the shock was felt by about 10 per cent of the people. Reports have been received from Nehalem, Tellamook, Newport, Salem, Gardiner, Drain, and Eugene to the effect that the shock was not felt. At Port Orford a slight tremor was felt.

Inland from the coast the following observations are reported by Mr. G. A. Waring:

At Grant's Pass the shock was slightly felt. At Medford a few people felt it, and one woman was awakened by a slight swinging of the partly open door. At Ashland the shock was lightly felt and the sulfur springs nearly doubled their flow for 24 hours, and then slowly returned to normal condition. A few people in Klamath Falls claim to have felt the vibration, but no clocks in a jewelry store were stopt. In Langell's Valley few, if any, felt the shock, but water in an east-west trough was noticed moving slowly from end to end. From two different sources it was reported that at Merrill the shock was distinctly felt, and two old buildings in this place are said to have been shaken down. It was reported that the shock was felt in Drew's Valley, but the people at the stage station there did not feel it nor know of any one in the valley who did. At Lakeview a seconds-pendulum clock facing south in a jeweler's store stopt. The clock was about half run down, it being near the middle of the week. The jeweler says it had never stopt before. One other clock, a spring one, was reported to have stopt in this town, and two or three people claimed to have felt the vibration. Mr. Waring could not, however, find any of these people. At Paisley no shock was noticed on April 18, but on Thursday, April 19, about $1^h 30^m$ A.M., a tremor was felt, strong enough to generally awaken people, and during the next hour and a half three more shocks were felt. Considerable excitement was caused, some people going out-of-doors and one rather delicate woman being made sick. But no doubt the fact that news of the San Francisco disaster reached here late the previous afternoon greatly increased the notice paid to these vibrations. Mr. Waring could learn of no clocks being stopt, the only material evidence being the shaking of a lamp from the edge of an unsteady center table. Enquiry failed to elicit any evidence of a shock having been felt at Bly, Bonanza, Summer Lake P.O., or Silver Lake.

Mr. Waring closes his report with the following general statement:

> Judging from all I could learn, I think over most of south central Oregon the vibration was hardly perceptible to people awake. At Paisley and at Merrill stronger shocks were felt. The shock at Paisley was peculiar in being early Thursday morning, April 19, a sort of "sympathetic" shock. No information concerning the time of the shock at Merrill was obtained, but I think it was on Wednesday morning at the time of the great quake. The greater intensity of shock at these two places is perhaps due to the underlying formation. Paisley is built on river ground at the edge of the Chewancan Marsh. Merrill lies in or near Langell's Valley, by Lost River, which here sinks and flows thru swampy land in several places.

KLAMATH MOUNTAINS AND NORTHEASTERN CALIFORNIA.

Crescent City, Del Norte County (George Sartwell). — The earthquake was felt as a northerly and southerly temblor lasting about 5 seconds, with a short intermission. Several pendulum regulators stopt. In the easterly portion of the town the water in a mill-pond was noticed to surge back and forth, disturbing the logs. The ground in the vicinity is of a springy nature. On the morning of April 23 another shock was felt, and

reported by some to be more severe than that of April 18. But Mr. Sartwell, having experienced both shocks, is of the opinion that the shock of April 18 was the heavier. The shock of April 23 was westerly and easterly, and a regulator clock in the shop of D. S. Sartwell, watchmaker, that stopt on April 18, was not stopt on April 23. The same action took place in the mill-pond as on the 18th. Many people felt neither shock. Each time there was a cessation for a few moments of the surf beating on the shore.

Klamath, Humboldt County (C. H. Johnson). — There were two shocks, the first being the hardest, and the direction of movement from east to west. The first movement seemed to lift up, the second to settle back and shake. No objects were thrown down.

Prof. A. S. Eakle reports that at Trinidad a severe shaking up was experienced, but the shock, according to the residents of the place, did no damage.

Mr. P. L. Young, M.E., who was in Eureka on the morning of April 18, shortly afterward traveled thru a portion of the Klamath Mountains. He reports that the shock was felt at Arcata, Blue Lake, and up Redwood Creek to Hower's. On the Bald Hills, at an altitude of 3,300 feet, the shock was heavy. At Martin's Ferry, on the Klamath River, two trees were shaken down. It was felt at Weitchpec, at the junction of the Trinity and Klamath Rivers, at Orleans, Somes Bar at the junction of the Salmon and the Klamath Rivers, at Bennett's at the forks of the Salmon River, and at Gilta, a mining camp in southwestern Siskiyou County, about 3,300 feet above sea-level. Seven miles from the latter place, at Brooks, in the extreme northwest corner of Trinity County, at an altitude of 4,800 feet, the shock is described as heavy. At Hower's, on the night of April 22, Mr. Young experienced another very perceptible shock.

Peanut, Trinity County (Mrs. Ellen Diller). — Mrs. Diller was in bed on the morning of April 18, partially awake, when she was aroused by hearing a heavy table dragged across the floor, altho she is quite hard of hearing. Attached to the ceiling of the room was a piece of wire about 3 feet long, to which a basket for flowers is sometimes attached. She noticed this wire swinging northwest-southeast thru a space of 7 inches, and thought the wind was blowing. The house shook as if a heavy person were walking in the entry. The clock was stopt, the clock facing the east and the pendulum length being 5.5 inches. Mr. John W. Diller at the time of the shock was awake in bed in a mining camp bunk, in a board shack about 8 miles east-northeast of Peanut. It seemed to him as if some one were pushing or pulling the side of the shack off. The man in the bunk below him was awakened but other sleepers in the shack were not.

Montague, Siskiyou County (G. H. Chambers). — There was one shock, the estimated duration of which was 30 seconds. The apparent direction of movement was east and west. The shock was strong enough to rattle windows, to cause beds to move, and suspended objects to swing. One clock was stopt.

Gazelle, Siskiyou County (O. F. Dyer). — Many persons in bed felt a light sensation. One clock in a brick store was stopt. The vibration was southeast and northwest.

Sisson, Siskiyou County. — Press reports state that some windows were broken and that water in the Southern Pacific Railway tank spilt out.

Dunsmuir, Siskiyou County (A. J. Pickehorn). — Doors and windows rattled.

Etna Mills, Siskiyou County (May Lemon). — Several clocks stopt and some plastering was cracked.

Slight shocks are also reported from the Black Bear, Cantara, and Hornbrook, Siskiyou County. At Sawyer's Bar a few clocks were stopt. At Upton a water tank 40 feet high turned to the west, tipping some water out, and then went back to the upright position, according to a report by G. R. Dixon. He was awakened by his building swaying north and south. A rocking chair swayed in the same direction, as did hangings on north and south walls. This was followed by more complex movements, giving rise to nausea.

Denny, Trinity County (E. E. Ladd). — The foot of the bed was raised, and then the head, indicating that the shock came from south to north. This was followed by a tremble which caused a rocking motion.

Big Bar, Trinity County (W. A. Pattison). — Mr. Pattison was in bed in a very strong block-house, which shook and made a crackling noise. His pendulum clock stopt. Nothing was overthrown. There was a tremor, then a stronger shock. The movement seemed to be from northwest to southeast.

Papoose, Trinity County (C. Blackmore). — An electric light bulb hanging by a cord about 4 feet long was swung in an arc of about 22 inches.

Alturas, Modoc County. Population 500. (C. B. Towle.) — The hanging lamps in a saloon were found at $5^h\ 20^m$ A. M. to be swinging east and west. A tub leaning against the house on the porch was thrown down. Some men camped near the town felt a tremble of the earth. Others in camp several miles from the town were up and heard the low sound of the earthquake, but did not feel the shock.

Susanville, Lassen County (James Branham). — Mr. Branham was in bed with his head to the north and felt himself roll back and forth in the bed, from which he concludes that the motion was east and west. The shock was, however, not severe enough to be generally felt by people asleep.

McArthur, Shasta County. — Two shocks were felt, the first the stronger, the motion being east and west. Nothing was overthrown, according to a report by John McArthur.

Stella, Shasta County (J. F. Schilling). — A pendulum clock in the Woodward Hotel stopt.

Redding, Shasta County (L. F. Bassett). — Mr. Bassett was indoors, squatted on his toes in front of a stove lighting the fire when the shock came. He felt no tremulous motion and only one principal disturbance, which lasted several seconds. There was a slight swaying motion of the house for perhaps 10 seconds, and this was strongest at the beginning. The motion tended to throw one toward the north. No objects were overturned, but the windows rattled a little. A rumbling noise preceded and followed the shock, which he ascribed at the time to a passing train; but there was no train due at that time.

(B. Macomber.) — The shock was not intense enough at Redding to move loose objects. In a few cases clocks were stopt. The shock was felt violently and many people were awakened by it. It was preceded at a very slight interval by a roar. Up to the moment that the most violent part of the shock struck the house, I was under the impression that the sound and the vibration were both caused by a train passing. The direction seemed to be from slightly west of north to slightly east of south.

Cottonwood, Shasta County (J. B. Heiderick). — A clock stopt.

HUMBOLDT COUNTY.

Arcata, Humboldt County. Population 950. — A. S. Eakle reports that a few chimneys were damaged. Mrs. William Nixon reports that a fissure opened in one of the streets of Arcata, into which her informant, a reliable man, said he could insert his hand; but by night it had closed again. She was also informed that a brick from a chimney was thrown 40 feet toward the south. The main shock appeared to her to be east and west; two rocking chairs in different rooms, both facing east, were observed by the separate occupants to rock violently. A clock on a north wall did not stop, while many on east or west walls did. Of two clocks on the south walls of the same house, one stopt while the other did not. Mrs. Nixon places the intensity in Arcata at VIII on the Rossi-Forel scale. She reports further that Blue Lake felt the shock to the same degree as Arcata, with falling chimneys, etc., and that shocks were felt up Mad River at Angel's Ranch and on Redwood Creek at the Berry Ranch. A later shock was felt at $1^h\ 10^m$ A.M., which stopt a clock on a north wall.

Eureka, Humboldt County. Population 7,350. (A. S. Eakle.) — Eureka was damaged to the extent of about \$5,000, according to report. Most of the signs of destruction had been repaired, but a walk thru the town convinced me that the intensity of the shock

was not great. There are numerous brick buildings, but no cracks were caused in any of them. The greater number of the chimneys were unaffected. In the Public Library no books were thrown from the shelves. The large statue of Minerva on the dome of the Court-house vibrated back and forth and finally rested at an angle of about 45°. Mr. A. H. Bell, of the Weather Bureau, made a note of the direction of the movement, which was southwest to northeast, and this direction was confirmed by other observers.

(A. H. Bell, Observer U. S. Weather Bureau.)—It was the most severe earthquake of which there is any record at Eureka. It lasted 47 seconds and the vibrations were from southwest to northeast. There were no preliminary tremors, the shock being sudden and the vibrations continuous, with maximum intensity toward the end. Buildings shook to an alarming degree and several were slightly twisted. One frame building moved about 12 inches to the west. Many chimneys toppled over and several hundred panes of glass were broken. There was no loss of life and loss to property did not exceed $8,000. Chimneys fell in all directions, but most of them toward the west. The statue of Minerva on the dome of the Court-house tipt toward the south until it leaned at an angle of 43°.

A second shock occurred on April 18 at $5^h 22^m$ A. M., and another was felt at $12^h 25^m$ P. M. These shocks were slight and of short duration. Slight shocks of earthquake also occurred in early morning of April 19; at 3^h A. M. on the 20th; $6^h 07^m$ A. M. on the 23d; $10^h 30^m$ A. M. on the 27th; and at $11^h 10^m$ P. M. on the 30th. There was quite a severe shock on April 23, at $1^h 10^m$ A. M., lasting about 14 seconds. The vibrations were from southerly to northerly, being of sufficient violence to shake buildings and stop clocks in different parts of the city.

(H. H. Buhne.)—People who were not frightened and who were looking out of their windows described the scene as looking as if all the houses were on the ocean. Only one clock stopt in my house and that was the large regulator in the hall, facing southwest. The other clocks had their pendulums swung southwest, so did not stop.

The shock lasted 47 seconds. It started from a southwest direction. The reason I am so sure of it is that I was passing by my mantel, and one of the statues hit me in the back when the quake started, and it could not have come from any other direction to have done this. It kept swaying the house back and forth for a while, and then wound up with a twister. My chimneys stood it until the twister came, and that made them crack. On examination I found them turned from 0.5 to 3.5 inches. They were all twisted from southwest to north. At my hunting house the shock threw a glass globe and chimney from a large Rochester stand lamp into one of the beds, in a direction about 4 feet from southwest. If it had come from any other direction it would have smashed the glass to pieces.

The damage in Eureka, outside of the Water Works, will not go over $10,000. Plate-glass windows were smashed in every place except the Buhne brick block. All the plate glass in this building rests on from 0.325 inch to 0.5 inch rubber. The shock picked up one building that stood on made ground and lifted it bodily 12 inches on to the next lot. This building was thrown toward the southwest. The statue of Minerva, 13 feet high and 187 feet from the ground, on the dome of the court-house, was thrown forward to an angle of 45°. She was bowing directly south. Chimneys went down everywhere, some thru the roof; others were twisted halfway round. No lives were lost and only one person was hurt by a chimney crashing thru the roof.

South of Eureka (H. H. Buhne). — A few days after the quake everything lookt all right along the road, excepting chimneys, until I reached Field's Landing, at South Bay. Here the shock opened a fissure over 100 feet long in the middle of the road, which 6 teams spent one day in filling. Pelican Island, as it is commonly called, opposite Field's Landing, dropt 3 feet at the point where the United States pile beacon stands. It left the beacon landing at an angle of 45° from the southwest.

At Dungan's Ferry, on the north bank of the Eel River, the ground was full of fissures. Every bar on the river had been opened by fissures, and the gravel toppled over leaving big ditches, some 6 feet deep and over 500 feet long. Coming up on the mainland the road had dropt about 2 feet in one place and was full of small fissures. A 40-acre field was entirely ruined. It was heavily fissured, having dropt down in strips from 2 to 6 feet wide, from 4 to 6 feet deep, and from 5 to 500 feet long, the fissures pointing between south and southwest. All the fields were full of quicksand volcanoes, some 1 to 3 cubic yards in size. They were perfect miniature volcanoes, every one having a crater. It is said they extended 30 miles up the river.

In Ferndale not a chimney was standing and every brick building was torn to pieces. The shock threw two wooden houses sideways. All the plate-glass windows were smashed.

Near the False Cape it threw the old hill, on which the Oil Creek coast road ran, out into the ocean for 0.5 mile. It is estimated that 200 acres were thrown into the ocean. Quite a number of cattle went with the hill. The slide is said to have obscured the view of Cape Mendocino light from Trinidad heads.

In Petrolia the shock threw every house off its foundation; in the mountains it opened great fissures, ruining many acres of good grazing land. It is said that the McKee ranch, near Shelter Cove, is entirely ruined by fissures. About 6 miles below the mouth of the Mattole River, at what is called Sea Lion Gulch, the mountains pitched together, entirely obliterating this dangerous place.

The amount of damage thru the county will not exceed $100,000. In the forests thousands of cords of redwood limbs are strewn over the ground and many of the trees were twisted off and hurled to the earth. A friend of mine living within 200 yards of a large body of redwood at Pepperwood, near Eel River, was in the field when the shock came. It lookt to him as if the tops of the trees were almost touching the ground when they were swaying back and forth. It made him quite dizzy to watch the trees. Limbs came crashing down everywhere, intermingled with an occasional terrible crash telling of the fall of one of the giants of the woods.

Freshwater, Humboldt County. To the east of Eureka. Population 150. — The shock is described by Mr. S. E. Shinn as heavier than the one he experienced in San Francisco in 1868. Not a chimney was left whole in the town or valley, and glassware in houses was generally broken. The first part of the quake was from east or a little south of east to a little north of west; then came the big wave, like waves of the ocean. The orchard was lifted between 2 and 3 feet as if by a big breaker coming in. At the same time he thought the house would come down; then it seemed to give a lurch and throw the chimney straight north, some of the bricks going 15 feet from the porch. He could not keep his feet except by hanging on the door knob, after being thrown back and forth.

Alexander Cœur states that most of the chimneys in Freshwater were thrown northeast. About half of the chimneys were thrown and the rest were all more or less shattered. Some were twisted from east to west and one was turned halfway around but did not fall. The town is at the foot of a hill near a small stream, and is built on gravel having a depth of about 6 feet.

Ferndale, Humboldt County. Population 850. — This town, on the south side of the flood plain of the Eel River, appears to have been the most severely shaken place in Humboldt County. It is the largest town in the county south of Eureka, and is about 2.5 miles from the Eel River, as it now flows thru its flood-plain, 0.5 mile from Salt River, a tributary of the Eel, and 9 miles from the ocean where the Eel River empties therein. The valley to the north of Ferndale, and extending east and west from it, is underlain by alluvium of probably considerable depth. It is very low and subject to floods almost every winter. South of the town are rather abrupt slopes rising to the summit of the ridge which ends in Cape Mendocino. These slopes are underlain by soft sandstones of

Pliocene (Merced) age, dipping uniformly northerly toward the valley of the Eel River.[1]

Mr. A. W. Blackburn, of Ferndale, writing May 2, 1906, contributes the following statement regarding the effect of the shock in that town:

There is general agreement here that the principal direction of the earthquake waves was from southwest to northeast. The main street of the city runs about southwest and the tremor swayed the houses and business buildings from southwest to northeast, breaking over two-thirds of the plate glass windows facing the street, while windows on the sides of the buildings did not suffer nearly so much. One 3-story frame building was caused to lean at an angle of at least 5° from the vertical. Most of the chimneys fell, not one in ten standing, and those that did stand were rendered insecure for the most part. They generally fell either toward the southwest or northeast, where the roofs slanted in those directions. Those who claim to have been out-of-doors when the shock came state that the earth rose and fell in great waves like those of the sea.

The only two brick buildings in town, both of which were one story, with a gable in front raised above the flat roof, had these square gables thrown forward into the street. One was a new building just finished this winter, and its walls were completely ruined, being cracked and loosened. Several buildings were lifted from their foundations, but for the most part the frame buildings were simply swayed out of plumb. Accompanying the quake was a rumbling, roaring sound. The tremor was short and jerky at its point of maximum intensity.

Prof. A. S. Eakle, who visited Humboldt County at a later date, corroborates the statements just quoted. He says:

At Ferndale the greatest amount of destruction in the county took place. According to Mr. Joseph Shaw and others of the town, the shock came from the southwest and the general direction of the fall of chimneys bears out this statement. There are 2 brick stores in the place, both of which had their upper portions thrown off. Some chimneys were thrown eastward a distance of 15 feet. Several of the frame houses were knocked out of plumb, but only one was moved entirely off its foundations, tho a slipping of a few inches was common. The main street runs northeast-southwest, and the stores on both sides had their plate glass windows demolished. (See plate 66A.) There were no cracks nor sinking of the land in the town and the damage was wholly due to the rocking of the houses. As most of the stores had large glass windows in front, the upper stories were weakly supported from lack of bracing, and this was primarily the cause of their bending out of plumb. Very few frame residences were seriously damaged. It was reported that a brick falling from the chimney of one house was thrown into the bedroom of the same house thru the upper half of one of the windows under the eaves. This illustrates the intensity of the rocking motion to which the structures were subjected.

On the flood plain of the Eel River to the north of Ferndale, Professor Eakle reports that the ground was cracked for a distance of 0.25 mile on the west bank of the river. The cracks were in close vicinity to the river, and seemed to be on the line of an old channel. A series of parallel cracks, some having a vertical displacement of 2 feet, the surface being uplifted and deprest, followed the trend of the river and were evidently local in the soft alluvium. At the time of the earthquake water and sand spouted up in several places thru openings which were in some cases 4 inches wide. Mr. Blackburn reports that this water remained on the surface of the fields for some time after the earthquake. In this same connection, Mr. J. A. Shaw reports that "a field on a high bar near the Eel River was literally shaken to pieces, and water filled with quicksand was ejected several feet high. The rents run from north and south in a curve to east and west. Some parts are actually cut into squares. The jump vertically will reach 2.5 feet. There were no such large rents thru the valley generally, as the upper soil rests on a clay foundation which seemed to stand it all right."

[1] For a geological section at this point see The Geomorphogeny of the Coast of Northern California, by Andrew C. Lawson, Bull. Dept. Geol., Univ. Cal., vol. 1, No. 8, p. 256.

Regarding other parts of the valley, Mr. Blackburn reports that all the other towns bordering on Eel River Valley suffered less than Ferndale. Loleta, on the northeastern edge of the valley, partly up Table Bluff, did not suffer severely. Fortuna, northeast-east of Ferndale, suffered less than Ferndale, tho only 6 miles distant; other towns up the Valley suffered still less. At Grizzly, population 70, 5 miles east of Ferndale, chimneys were thrown to the ground and crockery in the houses smashed, according to Mr. A. C. Matheson.

To the west of Ferndale, on the coast about 0.5 mile south of Oil Creek, a large landslide was caused by the earthquake and is described in the following note by Professor Eakle: "A section of the coast roughly estimated as one-third of a mile in length slipt on a 75° plane into the ocean, forming a point of land extending 100 yards or more into the sea. The slide destroyed a portion of the coast road which ran along the edge of the cliffs. The coast cliffs consist of Merced sandstone, dipping 45° to the north, and there is evidence that landslides have been quite frequent here in the past."

Cape Mendocino Light Station (R. Jensen). — The shock traveled from southeast to northwest. The light-tower and house were heavily shaken. The brick foundations and water cisterns, as well as the concrete in the yard, were broken.

Petrolia, Humboldt County. Population 200. (A. S. Eakle.) — Practically every house was thrown off its foundations. A moderate shock, however, could do much damage to the town, owing to its situation and the way the houses were constructed. The houses are built on the soft bottom land of the Mattole River, several of them within a few feet of the river, and their supports are simply blocks of wood, stone, or concrete resting on the surface of the ground. In the shake-up the blocks under the houses were unequally rocked and some became overturned, causing the houses to slip. The movement was in general east and west. Cracking of the land occurred along the edge of the river in close proximity to the hotel, which was quite badly damaged. Two houses on a terrace about 20 feet high, on the right bank of the river, were not injured as much as those below.

A note from Mr. Blackburn regarding this same town says that the only place which is reported to have suffered relatively more than Ferndale is the little town of Petrolia, on the Mattole River; there frame houses were moved from their foundations and even fell completely; the earth cracked very much and made wide fissures; many slides occurred and the shock was heavier. The general direction of the shock was from the southwest. The valley along the Mattole River is very narrow and the mountains are higher than near Ferndale.

From Petrolia to Shelter Cove we have the following note by Professor Eakle as to the destructive effects of the earthquake:

About 10 miles up the river at Upper Mattole, the ranch house of Mr. Roscoe was moved about 2 inches westerly and the chimney destroyed. At the town of Briceland, on the south fork of the Mattole River, the shock was severe but considerably less intense than at Petrolia. The store moved westward one inch and the stock was thrown from the shelves. Damage to the town was slight, and at Garberville, farther east, it was still less. From Briceland to Shelter Cove by stage road there are but two houses and these had their chimneys thrown off, but nothing more serious. No cracking of the land occurred except in the vicinity of the Cove. The buildings at Notley's, within 1 mile of the fault on the west side, suffered no damage. Even a terra-cotta chimney was not overthrown, altho it was knocked awry. Some of the furniture was displaced and some of the goods in the store were scattered about.

On the stage road between Eureka and Sherwood, Professor Eakle reports that the shock was sufficiently severe to throw some chimneys at the various very small settlements along the road, and that the general movement of the vibration in this section was reported to be easterly and westerly. The town of Fortuna suffered most.

Fortuna, Humboldt County. Population 1,100. (D. L. Thornberry.) — Many windows in stores were broken and the stocks of merchandise on the shelves were thrown down.

Drug stores suffered most in this respect, and bottles fell principally from the west side. Over half the chimneys in the town were thrown down. Several houses moved from 1 to 3 inches off their foundations. The river water swashed up on the banks. Fortuna is partly on the river bottom and partly on the hill slopes above, the Eel River being to the west of the town.

Pepperwood, Humboldt County (J. F. Helms). — In the stores and saloons 10 per cent of the property was destroyed by breakage, but on the farms of the neighborhood the damage was mostly confined to the throw of chimneys.

Briceland, Humboldt County. Population 150. (J. W. Bowden.) — The village suffered damage to the extent of $1,500 due to the breaking of chimneys, water and gas pipes, household furniture, etc. The village is on sloping ground on the creek bottom, the latter being in solid sandstone and shale, with the bedrock near the surface generally. One 2-story building 30 × 80 feet, standing east and west on a concrete foundation, was moved north 3 inches on the west end and south 5 inches on the east end.

On the east bank of the main Eel River, to the east of Laytonville (A. S. Eakle), the ground was cracked for a distance of 300 yards, the trend of the crack following the course of the river. The crack was merely local in the alluvial bank of the stream, perhaps 100 yards from the water. A long bridge crossing the stream at this place showed no effects of the shock and the few houses in the vicinity were not damaged in the least. Further east, at Covelo, the shock was not violent.

Thorn. — Dishes were shaken from shelves in houses.

NORTHERN MENDOCINO COUNTY

By E. S. Larsen.

In the territory from Laytonville to Covelo, and northerly to the boundary of Trinity and Mendocino Counties, the shock was sufficiently severe to awaken nearly all sleepers, to throw milk from pans, and to jar a few things from shelves, but not severe enough to do any damage to buildings. No chimney was reported as damaged. Most of the chimneys are of rough stone, tho a few are of brick. Some plate glass was broken in one of the stores at Covelo, but the building was in course of construction and the windows were temporarily and insecurely put in place. A large proportion of the residents claim to have heard a roar just preceding the earthquake shock, and several report the shock as beginning with a slow east and west motion, and ending with quick severe jerks. A man riding in the hills at the time did not notice the shock, but his horse stumbled repeatedly without apparent cause.

There were a great many earth cracks formed in the Round Valley region. Some were examined, but many had been obscured by the winter rains, while others were not visited on account of the heavy rain which set in and made it impossible to cross the streams or get about in the hills. About 20 miles north of Covelo, about section 2, township 24 N. range 14 W., on the Horse Ranch, and about 700 feet above the north fork of the Eel River, is a crack about 40 feet across and 600 feet long. At the southeast end a ridge of massive sandstone makes that part of the terrace somewhat wider. At either end are small gullies. At the back, to the northeast, a rather steep hill of sandstone rises abruptly from the terrace. Below, to the southwest, the terrace ends in a steep slope which shows evidence of repeated sliding and has several springs near its base. There are no trees on this slope, but the hill back of the terrace is covered with trees and there are some trees on the terrace, mostly on the hill side of the crack, altho several oaks 8 inches in diameter are on the side toward the river. The main crack is about 400 feet long. It is indistinct and disconnected at the northwest end, but gradually becomes more prominent till it reaches a point just beyond the center where the river, or southwest side, is 6 inches higher than the hillside, and there is an open gap of about 8 inches. It then

begins to die out and upon reaching the sandstone ridge turns about the edge of the ridge and continues about 100 feet more in the shape of irregular cracks along the ridge.

The rocks about this crack are probably all Franciscan. The sandstone extends for some distance in all directions and is usually shown only by fragments. Cherts, serpentines, and schists occur a short distance above and seem to be closely associated with the sandstones. The strike seems to be northwest and the dip quite steep to the northeast. No evidence of faulting was found, but the few outcrops showed little structure. The hills for a considerable distance on all sides of this crack are covered with old slides. Careful examination and enquiry revealed no extension of the crack in either direction.

The extension should pass fairly close to the road from Covelo, but none of the ranchers along the road knew of any cracks in the hills until Dobbins' place was reached, 10 miles southwest, on section 14, township 23 N., range 13 W. Here a crack 600 feet long, trending N. 25° W., occurs on a bench 150 feet wide, made up of soft alluvium gravel, etc., bounded on the northeast by a steep hill of serpentine; on the southwest by a steep slope to the creek 200 feet below, and on the northwest and southeast by bedrock ridges. The crack occurs near the outer edge of the bench and the creek (southwest) side is a few inches higher than the hill side. It does not continue into the hard rocks at either end. Between the creek and the hill the ground is soft, miry, and full of springs, while at the edge of the hill irregular cracks are sometimes seen, showing that the muddy flat had likewise settled relative to the hill and indicating that the soft central area had settled relative to the hard, dry slope toward the creek and the bedrock of the hill. The crack runs under the cabin where there was the greatest movement, but tho the cabin is on four pegs, it was not disturbed.

In the absence of a map it may be stated that this crack lines up very well with the one mentioned above and that the upthrow (?) is on the southeast in both cases. Both are in soft material and both are parallel to the streams. Moreover, the road and a majority of the ranch houses are roughly in this line, and cracks off this line would be more likely to escape detection. No cracks were found between Dobbins and Covelo. Several cracks were reported crossing the road from Covelo to Laytonville near the top of the hill to the north of Middle Eel River. They are said to continue at irregular intervals for a mile or more to the north or slightly north of west. They generally trend north to northwest, but vary considerably.

One mile farther west toward the Eel River, a crack crost the road toward the north. There is a strip of soft sandstones and shales thru here resembling that found at the Horse Ranch and striking to the northwest. In this strip numerous cracks were found, often trending northwest but varying considerably. Four of these cracks were visible, but others could not be found as the rains had healed them. It was said that the downhill or southwest side was sometimes higher than the northeast side. Only one of these cracks could be ascribed to a slide. The other three might very well have been due to the shock. Just north of W. Geforth's house is a crack 1,000 feet long, trending N. 55° E., and following roughly a low ridge running out from the main hills. It cuts almost at right angles to the main hills and is in soft material which has little slope. It could hardly be an ordinary slide.

On the top of the ridge, where the soft streak crosses the hills at an elevation of about 1,000 feet above the river, is a crack about 50 feet long just below a low sandstone knob, trending northwest partly across the draw at a considerable angle with the crest of the hills. It is irregular and shows no displacement of any kind. It could hardly be a slide.

Still farther north, just beyond E. Gevire's house and about 5 miles from Robbins, is another crack trending northeast. It is probably a slide. Mr. Gevire stated that there were several slides in the hills on all sides of his house, but no other cracks were reported to the north. To the south the cracks extended to the river, but none were known south of the river.

About a mile farther west, at Poon Kenney, several more short cracks were reported trending northerly but varying in direction, and not connecting along their trend, but I could not find any of these. About 6 miles north of the bridge on the Eel River, at a sheep camp called Hole-in-the-Ground, there are said to be a great many cracks running in various directions, but I did not visit them. On the whole, I believe that these cracks were all due to the earthquake, but that they are nothing more than surface cracks due to the jar. They occur only in the soft strips of weathered sandstone and where they seem to be related in trend they also seem to follow the strike of the rocks.

SHELTER COVE TO ALDER CREEK.

The intensity of the earthquake shock near the coast of Mendocino County, between Shelter Cove and the mouth of Alder Creek, is of peculiar interest, since along this portion of the coast the fault line is offshore at an unknown distance and has an unknown course, except in so far as can be indirectly inferred. One of the most important factors in the problem of determining the probable distance offshore at which the fault line traverses the floor of the Pacific is the intensity of the shock as experienced at points along the coast. Fortunately we have satisfactory information on this point.

Monroe, Mendocino County (D. Besecker). — About 90 per cent of all brick chimneys were thrown down. In houses with shelves and cupboards arranged east and west, 50 per cent of all dishes and glassware was broken. Stores with shelving running the same way had all goods thrown off the shelves. Many buildings of light frame construction were moved from their foundations. This place is in the heart of the great redwood forests, where trees attain a height of 300 feet or more. These tall trees suffered more from broken tops than anything else; few if any sound trees were entirely uprooted. The trees swayed to and fro for fully 10 minutes after the shock. The direction of the motion was north and south. Fissures opened in the mountain sides, and during the present winter (March, 1907) many large landslides have resulted from these openings.

Hardy (Alice Kingsbury). — My chimney was thrown down. Many dishes in surrounding houses were broken. My piano was moved 8 inches from the wall. The earth was cracked, both upon the mountains and near the creek, where the earth was broken away from the banks. The logging railway in the woods was somewhat damaged. The walls around the boilers in the lumber mill were cracked.

Westport (M. M. Bates). — All but one of the chimneys in town were shaken down. Large tanks that were on the ground were destroyed, but those built on framework were not damaged. Large cracks were made in the ground, and after the heavy rains of this winter (March, 1907), large landslides occurred. Goods were thrown off shelves in the store. (The town is quite near the ocean on a wave-cut terrace underlain by rock.)

Inglenook, Mendocino County (E. Pitts). — Not a chimney was left standing, nor were dishes enough left to eat breakfast on. The town is between the ocean and a belt of timber. Much of the timber fell, owing to the violence of the shock. On the banks of a small lake in the sandhills between the town and the ocean, some alders and willows fell owing to a slumping of the banks.

Cleone, Mendocino County. — Most of the chimneys in the place are terra-cotta. All the brick ones fell. About $200 worth of breakable goods in a general merchandise store was totally destroyed, and about $300 to $400 damage was done to the wharf and railroad tracks. All sway-braces on the wharf had to be replaced, and the railroad track was buckled in many places. The bridge across the lagoon sank 3 feet in some places, and was thrown out of line laterally, all the piling supporting the bridge being listed to the south.

Branscomb, Mendocino County (J. M. Branscomb). — Of about 15 chimneys in the vicinity, 2 were shaken down.

A. Wrecked stores. Ferndale, Humboldt County.

B. Wrecked buildings, Fort Bragg. Looking northwest.

A. Odd Fellows' Hall, a 3-story brick building. Fort Bragg. Looking east.

B. U. C. Co.'s mill, Fort Bragg. Smoke stack 5 feet in diameter. Entire structure thrown out of plumb to south, 1 foot in 20 feet.

Fort Bragg, Mendocino County. Population 1,600. (F. E. Matthes.) — The town of Fort Bragg suffered quite severely, and the indications are that the intensity of the shock was considerably greater than in the towns immediately to the south. Several brick buildings were completely demolished; others had parts of their walls broken off. Even a number of wooden buildings collapsed or were partly wrecked. Fire broke out and devastated 1½ blocks before it could be controlled. The water mains were disconnected and the entire town might have been wiped out but for the timely assistance of the steamer *Higgins* in the harbor. The mill lost its iron smoke-stack, and was temporarily crippled. In all, the damage thru fire and earthquake is estimated at $100,000. (See plates 66B and 67A, B.)

The following more detailed account of the effects of the shock at Fort Bragg is supplied by Mr. O. F. Barth, principal of the Fort Bragg Union High School:

The first shock had an oscillatory motion. A temblor was felt about 2 hours later, and from 1 to 3 temblors have been felt at irregular intervals nearly every day since.

The direction of the wave of the heavy shock appears to have been toward north by east. The principal fact that justifies this statement is that the monuments in the cemetery, with but two exceptions, fell from their bases south by west. A second reason is that a cylinder printing press weighing not less than 5 tons moved about 3 inches south and 2 inches west upon a level floor. The part of the building containing the press has been finished only a few months, has a strong wooden beam foundation, and was not moved out of position. About a block away a safe in such a position that it could not move in the direction of its rollers, north to south or the opposite, was thrown off its blocks westward 3 or 4 inches. At the high-school building (temporary quarters, not moved at all), a large case about 2×4×7 feet, full of apparatus and instruments used in physics, moved (rolled out) toward south by west, but nothing was upset within. This case stood close to a central partition on the north side of a south room on the second floor. Chemicals on open case shelving on the outside (south) wall of said room were nearly all thrown to the floor.

At Noyo, 1.5 miles from the center of Fort Bragg, a store 1-story high, having but a floor space of several rooms, perhaps 50 × 60 feet, on underpinning averaging 3 feet high, moved about 22 inches west and nearly as much south. This store stands within 100 feet of the Noyo River. At Fort Bragg most chimneys were broken off at the roof and most of them fell southward, but in a few cases they scattered around the shaft. Those built up from the ground, as a rule, fared worse. The large smoke stack at the saw-mill fell south by west. The brick foundation of a battery of boilers placed north and south was shaken down; another battery close by, facing east and west, was not affected. A large engine with a well-built brick base did not move, nor did the base, nor did the latter crack.

In my house and in several others, dishes on east shelves fell to the floor, while those on shelves on the other sides were less affected, those on the south hardly at all. The south shelves of two jewelry stores fared differently, all the small alarm and other light clocks falling out. In a drug store, one block north of said jewelry store, the north and east shelves suffered most, the north the more; but this may have been due to the difference in the bottles and packages, and to the additional jar of a falling brick building.

Several 2-story wooden store buildings facing west were thrown to an angle southward, the base remaining on the foundation, and the second floor moving from 0 to 20 or more inches. The upper story in most of these remained plumb. Eight brick buildings were shaken to the ground; two are being taken down. A new brick 1-story bank building is badly cracked, and only one brick building, 1-story, is intact. Of the eight, three were 2-story buildings. Many residences were moved, a few as much as 20 inches. Both 1-story and 2-story square built wooden buildings held their own well, except for their chimneys. The four wooden church buildings facing west, and the one facing south, are intact, save chimneys.

One man walking on the street was thrown down. He is positive the wave traveled southwest, the ground undulations being 2 and 3 feet high. Another lookt out of his door toward town, facing southwest. He says the wave traveled in that direction and a roar accompanied it, appearing to go farther that way each second.

At the cemetery, one four-piece monument dropt its top piece to the north by east, and the next two pieces as in other cases. The flat or ordinary grave-stones facing east are all intact.

In the press-room referred to, a bond fire extinguisher was apparently thrown or whirled from a southeast corner shelf out near the center of the room, and right side up. This would bear out the idea of a twist or double movement contraclockwise, apparently experienced by several people, myself included.

There are a number of fissures in the mud flats in and near the Noyo River and Puddin Creek. The boys say there are cracks in the streams. There are cracks in the less solid rocks along the ocean shore line.

(Eri Higgins.)—My house faces west. The east part was moved 6 inches south, breaking water and sewer connections. The west end of the house did not move. Goods on shelves were thrown from the north side, but not from the south side. All brick buildings in town went down except two, and these were damaged.

The above facts indicate that the destructive effects were as severe at Fort Bragg as at any other point within the zone of high intensities, but it is necessary to know something of the situation of the town. Experience elsewhere in the zone of destructive effects has shown that much damage may be caused to buildings even at considerable distance from the *locus* of disturbance, if they are upon soft alluvial bottoms. An inquiry was accordingly directed to Mr. Barth as to the situation of the town and its underlying formations. In response to this inquiry, Mr. Barth replies as follows:

Fort Bragg is mostly on the first terrace. The bluffs rise about 40 to 50 feet above the sea. Then the terrace has a gentle slope thru the town up to the second terrace (a rise of 60 to 75 feet above cliffs), which begins about where the built-up part ends. There is no distinct line of division, but a more rapid rise for a few hundred feet marks the second terrace. It is about 0.25 mile on an average from the bluffs to where the town really begins, *i.e.* going eastward; and the town has a width of a little more than 0.25 mile, from here to the second terrace, still going eastward. The sea-cliffs are rough, rocky, perpendicular walls, or nearly that, for several miles, with many bold, rocky, tooth-like sea-worn isles skirting them.

About half a mile north of town, Puddin Creek, and about a mile south of town the Noyo River, have cut their way thru rather deep canyons to the sea. While the volume of water in the latter is larger, the narrow valleys of the two do not differ much. Narrow strips of tillable land skirt them. The two almost meet about 3 miles east of the bluffs, where there is a narrow divide and where the third terrace appears to begin. There is a gradual rise from the second to the third terrace.

The surface soil upon which Fort Bragg is built consists of a sandy loam, rather sandy and yet pretty firm. The laying of sewer pipes 4 to 6 feet deep reveals more sand below, of a dark yellow color. At the bluffs or cliffs there is from 10 to 15 feet of soil. At one point where the second terrace begins (here Puddin Creek curves in close to town), solid rock comes close to the surface.

A well about 500 or 600 feet north of the business center reached rock at 30 feet. One of the brick buildings, a 3-story hotel which was so badly injured that it had to be taken down, stood about 100 feet from this well. Another well, 0.25 mile north of the business center, obtained water in sand at a depth of 22 feet without reaching rock.

The town is comparatively level from north to south, except for a small valley — hardly that — a 0.25 mile wide vale, running down thru the mill yards to the sea at the point where the harbor indents the coast.

It is clear from this description that the town of Fort Bragg is on a well-defined wave-cut terrace carved out of the hard sandstones which prevail along this part of the coast, and that the terrace is mantled with Quaternary marine sands varying in thickness from 10 or 15 feet at the brink of the present sea-cliffs to 30 feet in other parts, and tapering to nothing at the rear of the terrace. It therefore seems to be a fair inference that the destruction experienced at Fort Bragg is not due, except to a very limited extent, to those causes which work exceptional damage in the water-saturated alluvial bottoms; but that it is referable to the high intensity of the shock, thereby implying proximity of the town to the fault.

(W. T. Fitch.)—There were several small cracks across the roads a few miles south of Fort Bragg; and back in the hills there were more and larger ones. In the bed of the Ten-Mile River, 10 miles north of Fort Bragg, where level surfaces occurred before,

there were noted after the earthquake funnel-shaped depressions resembling extinct volcanoes in miniature. These were only a few feet in diameter.

At Glenblair, 5 miles east of Fort Bragg, the intensity of the shock appears to have greatly diminished. The place is on a creek bank, between high hills. Mr. A. P. Scott reports that the saw mill was slightly damaged and that the store goods were thrown from north and south walls.

Caspar, Mendocino County. Population 300. (F. E. Matthes.) — The shock was apparently not so severe. Most of the wooden houses showed no damage. Even the large brick store of the lumber company appeared little affected. It was probably well built and sustained only a few cracks of little importance. All chimneys were broken without exception. The bridge over Caspar River is a total wreck, but it appears to have been a weak structure to begin with.

Mendocino, Mendocino County. Population 900. (F. E. Matthes.) — This town, like Fort Bragg, is on the first of a series of wave-cut terraces which score the coastal slope. The present sea-cliffs at the lower margin of this terrace vary from 30 to 100 feet in height. The terrace is veneered with Quaternary marine sands which are in part so compacted and coherent that they may be designated sandstones. The town shows but little damage. Only one large frame building, the Occidental Hotel, was wrecked thru the giving way of its underpinning. Few chimneys escaped destruction. Plaster fell in quantities in some dwellings, while others suffered but little in this respect. Only one out of a considerable number of water-tanks was wrecked. In the river bottom adjoining the town the destructive effect was notably greater. The lumber mill of the Mendocino Lumber Company was the chief sufferer. It lost its tall smokestack, and in addition had its large fly-wheel in the engine-room broken by the shock. This fly-wheel was oriented almost east and west on a north and south axis. According to the engineer, it was not in motion at the time of the quake. The oscillations of its exceedingly heavy rim caused the fracturing of the spokes in the two upper quadrants. The fragments were still visible in the mill yard.

The bridge over the Big River was also severely damaged, a short span in the long approach on the north side collapsing entirely. The structure had been repaired at the time of the visit.

(O. H. Ritter.)—Vibrations at Mendocino seemed to be oscillatory, moving north and south. I remember the feeling clearly, for my bed extends north and south, and moved in a straight line north. The high-school building was moved on its foundations about 2 inches north, and a 3,000-pound safe in town rolled north 3 to 4 inches. The wing of Occidental Hotel which extends east and west collapsed; while the wing extending north and south remained standing, altho the foundation braces were thrown slightly out of plumb in a north and south direction. It is very clear here that the vibrations were north and south. The day after the shock there were numerous cracks in the ground. Chimneys seem to have fallen north and south, generally south; numerous slides on the cliffs took place, some very large. The road between Point Arena and Mendocino was cut off by numerous slides (report of tourist). The bridge across Big River, extending north and south, collapsed. The fall of the span was due to the shifting north of the piles on the north side of the river, thus allowing one end to drop.

(William Mullen.)—The shock at Mendocino began with a tremulous motion, increasing very quickly and decreasing also quickly. The principal disturbance was strongest toward the end. The motion seemed to be up and down, and also from north to south. Chimneys fell mostly to the north, while tombstones fell to the north, south, and east. It lasted about 40 seconds. Beds were moved from 3 to 5 feet and pianos to the same extent. Pictures hanging on walls showed marks of having swung 8 inches. A rumbling sound like distant thunder preceded the shake, and was loudest at the commencement of

the movement. During the shake animals became greatly excited; horses and cattle ran about. Water in some wells became muddy and frothy.

Navarro, Mendocino County (F. E. Matthes). — This town is an abandoned one, and the conspicuousness of its damage may perhaps in large measure be attributed to the neglected state of its buildings. Nearly every house, except for the few still occupied, suffered partial collapse of its underpinning, so that from whatever point the town be viewed, it presents the same remarkable jumble of leaning, half-ruined houses. Its location on the flat, alluvial bottom next the river probably contributed to the severity of the damage. In fact, of the entire series of villages and towns visited on this section of the coast, this is the only one that stands on alluvial ground; all the others are built on firm rock terraces. The great wooden bridge at Navarro showed no damage whatever.

Greenwood, Mendocino County (F. E. Matthes). — Weak underpinning caused the partial collapse of several frame houses. Chimneys had fallen without exception. Plaster fell in the lower stories of the few houses containing plaster. The lumber mill was not damaged. Windows were broken in the hotel. If the fault line be produced northward with the last bearing observed, N. 28° W., it will be found to pass about 2.5 miles to the west of Greenwood; that is, nearly the same distance which separates Point Arena (*i.e.* the town of that name) from the fault. Yet the destructive force seems to have been a little less effective here than at Point Arena.

Albion and Little River, Mendocino County. — These two small settlements to the north of Navarro are compared by Mr. Matthes with Greenwood. He states that the damage at Albion was on a par with that at Greenwood. Only a few of the weaker wooden houses were crippled by the partial collapse of their underpinning. The bridge suffered but little damage. At Little River the intensity of the shock seems to have been less than at Albion or Greenwood.

Mr. James Coyle, of Albion, reports that he was on a hillside at an altitude of about 500 feet. He heard a roaring noise similar to a heavy fall of hail coming from the ocean to the west. The earth shook back and forth. He was thrown violently to the ground, as were also several cattle and horses that were grazing near. Large rocks were seemingly squeezed out of the hillside and rolled into the river. The trees were shaken northwest and southeast. He noticed only one maximum of intensity. Many houses and bridges were thrown down, chimneys all fell, and large landslides blocked the roads.

Bridgeport, Mendocino County. — An extensive landslide came down into the cultivated fields on the flat, wave-cut terrace east of the road.

ALDER CREEK TO FORT ROSS.

Manchester, Mendocino County. — Population 75. Nearly all the information that we have regarding the intensity of the earthquake shock for the coastal strip between the mouth of Alder Creek, where the fault enters the shore from the Pacific, and the point near Fort Ross, where it again leaves the shore, is contained in a report by Mr. F. E. Matthes. This is, however, supplemented by notes by Mr. W. W. Fairbanks, of Point Arena, for the phenomena observed in the vicinity of that town and by other observers in the vicinity of Fort Ross. In the following pages the statements regarding this territory will be understood to be extracts from Mr. Matthes' report, unless otherwise stated:

Manchester, a small settlement with a population of less than 100, only three-quarters of a mile west of the fault, was severely shaken, yet none of the frame houses in the village itself was badly damaged. A number of them slipt on their foundations, a notable case being that of W. W. Fairbanks' dwelling, which was twisted off its concrete supports, so that one of its corners was found 4 feet from its original place. The rotation was right handed. East of Manchester several farms were visited which were directly on the line

A. Point Arena. Brick house destroyed; wooden houses little affected. F. E. M.

B. Wreck of suspended flume across Garcia River. Looking west. F. E. M.

C. Collapsed wagon bridge over Gualala River. South end dropt 20 feet. F. E. M.

A. Sound redwood tree snapt off 42 feet from top. Near Fort Ross. F. E. M.

B. Redwood tree snapt off. Locality, 0.25 mile east of fault above Fort Ross. F. E. M.

C. Uprooted tree, 8 feet in diameter, 187 feet long, about half mile west of Garcia River, on road to Garcia Mill. Tree sound. F. E. M.

D. Bridge over South Fork, Gualala River, 3 miles east of Stewart's Point, looking north. Bridge floor and panels bent; tension rods buckled. F. E. M.

of the fault. A large barn at E. E. Fitch's ranch, thru which the fault past, was practically demolished. The animals in the barn fortunately escaped uninjured.

At Antrim's ranch, on Alder Creek, a tall shed stands on the line. It threatens to fall, but was still up at the time of the visit (May 10, 1906).

The wagon bridge over Alder Creek (plate 32B), which stood astride of the fault, is a complete wreck. The timbers broke in many places, and the tension rods were twisted and in some cases actually ruptured.

Along the Garcia River, the flumes of the L. E. White Lumber Company were reduced to kindling over long distances. Where they crost the river, suspended from steel cables, the end supports of the latter failed and let the flume drop down to the river-bed.

Farther up, between the lumber camp and Hutton's ranch, extensive landslides occurred, chiefly on the east side, wiping out the wagon road which was graded along the mountain slopes. Immediately north of Hutton's ranch, a large landslide plowed into a grain field, producing a series of billowy wrinkles in the soft alluvial material. The outermost ridge has a steep front about 8 feet high and seems to have been thrust horizontally over the level surface of the field. The frontage of the slide is fully 400 feet. Hutton's ranch-houses were all so badly damaged as to become uninhabitable; they are practically wrecked, tho still standing.

Reports from Hot Springs, east of the Garcia, seem to indicate that the buildings there suffered but slight damage. The springs themselves had not been affected by the shock.

From Alder Creek to Irish Gulch, and for a short distance north, rock slides are a common feature and cracks in the ground, frequently traversing the stage road, due to the slipping and settling of large masses on the steep hillsides, are too numerous to be reported in detail. On both sides of Irish Gulch the road was obstructed by slides which had been removed at the time of the visit, but which threatened to recur.

Reviewing his observations as to the intensity between Fort Bragg and Manchester, Mr. Matthes concludes as follows:

The gradual decrease of the intensity as one travels northward from Manchester is to be expected, in view of the gradually increasing distances of the several settlements from the line of the fault (it being supposed that the latter continues with the bearing measured near Alder Creek, N. 28° W.). On this supposition the decrease in intensity should, if anything, become more marked from Mendocino on; but such is evidently not the case. While the intensity does not materially differ at Caspar, it notably increases toward Fort Bragg; so much so, indeed, as to suggest a gradual curving of the fault, roughly parallel with that section of the coast. It is to be noted that over the distance between Fort Ross and Manchester, some 4 miles, the azimuth of the fault-line decreases steadily from N. 46° W. to N. 28° W. This gives a total deflection of 18° in 48 miles. Assuming that the curvature continues northward at a uniform rate, there will be in the latitude of Fort Bragg, 35 miles farther north, a further decrease of the azimuth of nearly 13°. The fault, therefore, may bear only N. 15° W. in that neighborhood. Plotted on a map, the line with such a curvature appears to pass 5 miles west of Fort Bragg.

Point Arena, Mendocino County. — Population 300. All the brick buildings in the place had completely collapsed (see plate 68A), and in the opinion of the residents it was deemed wisest to replace them by frame structures. All brick chimneys had fallen; plaster had cracked and fallen wholesale fashion, especially on the lower floors, and many shop windows and smaller panes were broken. A few wooden buildings suffered from the collapse of their underpinning. As a result of the shock, fire started in the chemical laboratory of the grammar school, and that building, together with the Methodist Church adjoining it, burnt down.

The Point Arena light-house, 3 miles west of the fault, was thrown out of the vertical, and in addition sustained several horizontal cracks thru its masonry. It has been condemned as unsafe and is to be torn down. The keeper's dwelling suffered little damage, one chimney showing cracks, the other appearing intact. The fog signal was not damaged. On the south side of Point Arena harbor, large masses of rock slid down to the beach. Small rock slides took place all along the coast in this neighborhood. A suspended flume over the Garcia River was wrecked (plate 68B) and large trees were overthrown (plate 69C).

This account by Mr. Matthes of the effects of the earthquake in the vicinity of Point Arena is supplemented by the following account of the destruction effected in the same territory by Mr. W. W. Fairbanks, who was on the ground at the time of the shock. His note covers the section of country from Alder Creek on the north to the town of Point Arena on the south, a distance of 7 miles, and from the coast eastward 1.5 to 2 miles. The note is dated May 5, 1906.

The country described is low and flat, sloping gradually to sea. The coast from the mouth of Garcia River north to Alder Creek is low and flat, with sand-dunes. South of the Garcia, high and rocky bluffs occur, except at Point Arena Harbor, which is at the mouth of a gulch running east to the mountains, the town of Point Arena being on the northern slope and bottom of gulch. Three creek bottoms are embraced in this territory, with higher ground between, somewhat rolling and with outcroppings of rocky ledges underlying.

Nearly every house in the territory described was injured, wracked, or moved more or less. The interior damage was severe. Stoves were thrown down and smashed into fragments. Nearly all chimneys were thrown to the east. Many wind-mill tanks were thrown down, those not containing water generally escaping. All church steeples stand intact, tho in some cases separated from the buildings. All old and flimsy buildings, barns, etc., escaped with least damage, many showing no injury or movement. Strong and stiff frame buildings suffered most. All brick buildings in the territory were thrown flat to the ground, except the government dwelling and light-house at Point Arena. Many frame buildings in Point Arena were utterly demolished. Buildings on or near rocky ledges, or buildings upon high ground with underlying rock formation, suffered the least; buildings on soft ground or creek-bottoms suffered most severely.

The shock came from a southeasterly direction. A heavy roaring sound preceded the shock. The ground moved in undulating swells or waves, rising and falling. Men and animals — horses, cows, etc. — were thrown to the ground, and were unable to rise or stand during the shock.

A great crack or fissure in the earth, starting from the sea-coast at the mouth of Alder Creek and extending in a direct line about southeast by south, termination unknown, past under the large wood and iron bridge over Alder Creek, throwing it into kindling wood. It past under the corner of the barn on Antrim's ranch, wrecking same. It then past thru a potato field, and a large section of same sank about 4 feet. Farther on, it past under a water pond and the pond went dry, tho the water returned in a few days. It past under another barn, a large frame building, and utterly demolished it. All the section of country on the westerly side of the crack moved northwest about 8 feet. Buildings on the east side and near the crack suffered but little; in fact, the section west of the crack received practically all the damage. The crack was about 4 feet wide in places, and the ground was thrown up in a great ridge, as by a gigantic plow.

In Manchester nearly every house was thrown west from 1 to 20 inches. There was one exception, however. A strong new frame house, 2-story, was thrown from its concrete foundations, the rear end swinging to the north and east 5 feet, the northwest corner acting as a pivot and remaining on its foundation pier. The house is built on soft ground near the creek bottom, with quicksand formation underlying. The woodshed and other outbuildings on same lot were thrown and swung in the same direction, but in less degree. Another house, 0.5 mile due east, on the same creek-bottom, swung to east and north, showing the same circular motion, tho moving but a few inches.

Point Arena light-house, erected 1870, a brick tower 110 feet high on a high, rocky point, is still standing but dismantled and condemned. It was broken clear thru in sections, as shown in fig. 49. It leans slightly to the north. The keeper on watch in the tower says:

"A heavy blow first struck the tower from the south. The blow came quick and heavy, accompanied by a heavy report. The tower quivered for a few seconds, went far over to the north, came back, and then swung north again, repeating this several times. Immediately after came rapid and violent vibrations, rending the tower apart, the sections grinding and grating upon each other; while the lenses, reflectors, etc., in the lantern were shaken from their settings and fell in a shower upon the iron floor."

Iron rods, supports, railings, and brackets were bent, broken, twisted, and thrown from their positions, making the wreck complete. The dwelling-house, a strong brick structure 50 feet distant, is badly cracked. Chimneys were not thrown, but one on the north was badly broken. The fog signal, 50 feet west of the tower, a wooden building containing heavy

machinery — steam-engines, etc. — was not affected in the least. A high wind-mill and water-tank, 0.25 mile southeast, were unaffected. I am convinced that the shock was comparatively slight here, owing to the solid rock formation underlying. Had it been as severe as at Manchester (3 miles distant), or Point Arena (4 miles distant), both tower and dwelling would have been thrown into ruins.

In Point Arena all brick buildings were thrown to the ground. Main Street runs north and south; all stores and business buildings (wood) on the east side of the street remained comparatively stationary, but all windows facing west in same were smashed, even the sash being thrown into fragments. Interior damage was great. Buildings on the opposite (west) side of the street and facing east suffered no breakage of windows, but nearly all moved west from a few inches to 2 feet. All chimneys were thrown east.

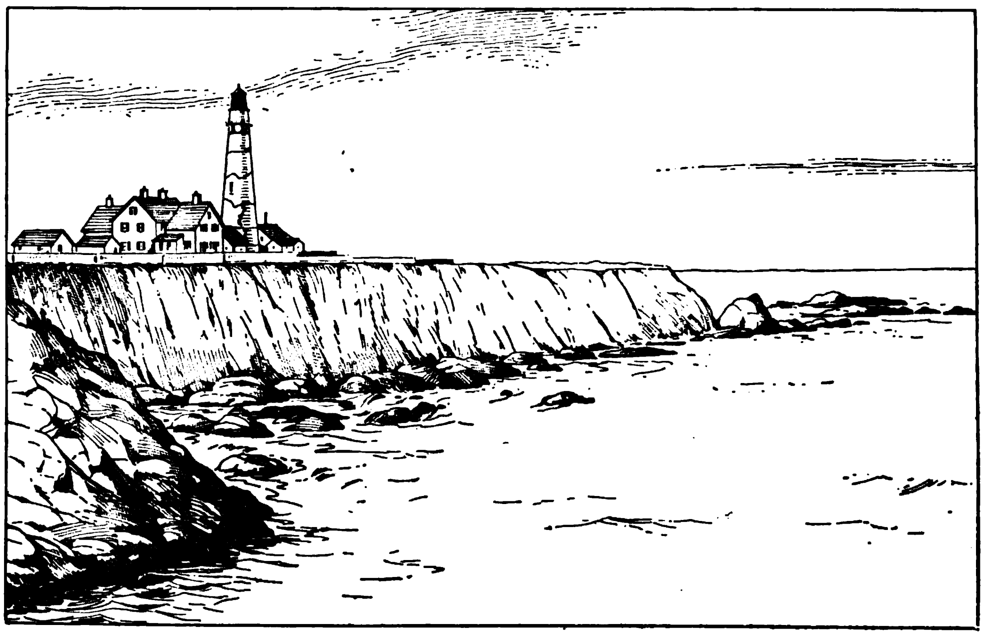


FIG. 49. — Cracks in light-house tower, Point Arena.

Buildings lower down on the slope as a rule suffered more, tho several wooden buildings high up, with underlying rock formations, were also wrecked. Nearly all buildings thruout the town moved west or northwest. In many cases houses drifted away and left porches standing in their old location. On the creek-bottoms many small cracks or fissures appear, thru which fine slate-colored sand has been forced to the surface, forming cones.

Between Point Arena and Gualala there are few dwellings and little of a definite nature could be ascertained by Mr. Matthes in his examination of that section.

At Fishrock, population 75, Mr. James F. McNamee estimates the damage at $1,000. The town is on a terrace of the coast 150 feet above sea-level on rocky ground.

Gualala, Mendocino County. — The wagon bridge over the Gualala River, south of the town, was seriously damaged. It consists of a trussed three-span structure 500 feet long, with a wooden approach of similar length built on trestles 20 feet high thru the swampy bottom-lands on the south side. This approach collapsed completely, the trestles being thrown flat and carrying with them the south end of the main span. The latter, however, did not leave its northern abutments and appears otherwise undamaged. It is considered safe to travel over, altho the bridge floor is now steeply inclined to the south. (See plate 68c.) In the town, population 75, all chimneys broke off; plaster cracked in the hotel and several other buildings; a few small dwellings were thrown off their underpinnings. Household articles and furniture suffered severely, most of the crockery and glassware in the town being destroyed.

A number of landslides blocked the wagon road and railroad track north of the river. A particularly extensive one occurred north of the junction of the branches of the Gualala, burying the tracks under many tons of rock and loose débris.

The railroad tracks of an abandoned logging road west of the Little North Fork show the effects of intensive longitudinal compression. The fault itself was 100 feet east of and parallel to the track along the stream bed, yet the rails have in several places been jammed lengthwise with sufficient force to cause sharp buckling. Stumps and cliffs on both sides of the track prevented the wholesale lateral sliding of the ties and localized the motion to a shifting of the ties a few feet lengthwise here and there. The kinks were so sharp as to cause the rupture of both rails in one place, and of the fish-plates joining the rail-ends in another. The track was narrow gage, with light rails, probably not exceeding 30 lbs. to the yard. In all 6 sharp kinks were counted within a distance of about 300 feet. (See plates 33C, D.)

Annapolis, Sonoma County (G. W. Fiscus). — Buildings were destroyed and bridges wrecked in this neighborhood; landslides occurred and the waters of the Gualala River were thrown out 50 and 60 feet on a gravel bar. The river rose 12 or 14 inches in a few hours after the shock. The motion was from southwest to northeast. It started like a wave and then assumed a rotary motion, tearing and grinding. The formations underlying the ranch are said by Mr. Fiscus to be hard-packed sand below the surface soil to a depth of 20 feet, then solid hard rock, as shown in a well 35 feet deep. In this well the earthquake broke out chunks of rock on opposite sides from within 10 feet of the top clear to the bottom. The line connecting the displaced rock on the two sides has a bearing of S. 30° W.

In several places along the line of the fault fissure, the earth has opened so as to allow gravel to fall into the cracks. In other cases water and sand were shot out of the openings, the sand remaining. Chimneys were thrown to the southwest.

Stewart's Point, Sonoma County. — The shock was felt very severely here and resulted in the destruction of an unusually large barn, formerly a lumber mill, used for the housing of lumber wagons. The structure was leveled to the ground. Small wooden dwellings were but little affected. All chimneys were damaged and the hotel lost the plaster from the walls of the lower floor. In the upper story the plaster sustained only a few cracks. The village lies about 2.5 miles west of the fault.

East of Stewart's Point the bridge over the South Fork of the Gualala River (plate 69D) was damaged by the slumping of the river terrace on which its south end rests. It was subjected to a strong longitudinal, compressive stress, which resulted in a slight upward buckling of the bridge floor near the southern end, and marked bending and twisting of the tension rods in the 2 southernmost panels. The supports at the south end furthermore appear to have settled 13 inches, causing the floor and the last panel to assume a marked inclination. A hundred yards east of the wagon bridge is an older, dilapidated one, whose floor has been removed for some time. Its rickety aspect and crookedness render it an unsatisfactory object for study in this connection. There is, however, clear evidence of the slumping of the terrace at its south end, in a manner similar to that at the new bridge; yet the old bridge appears to have stood the compressive stress better than the new, and its south end has merely overridden the displaced masses of the terrace.

On both sides of the sharp bend of the river east of the two bridges are extensive landslides, making a clean sweep down the mountain side. The slide on the north side completely blocked the wagon road and was being removed at the time of the visit (May 12). It is of such a height and steepness as to menace the road at this point with renewed sliding in future, especially during wet weather.

Gualala Valley. — At Casey's ranch, half a mile west of the fault, the destruction was notably severe, one building having entirely collapsed, and the dwelling-house having

been badly strained by the shock. The ranch stands on the east edge of the ridge, west of the Gualala River, and the fault runs along the mountain side several hundred feet below it. The slope is a steep one, densely timbered except for its upper portion. Landslides were found over a large part of its surface, but only in a few isolated spots had they resulted in the complete removal of the original surface and the forest growing thereon; so that a view from across the river revealed no appreciable changes in the landscape. The slopes east of the river were similarly affected and the fallen timber produced a tangle not unlike that of extensive windfalls. In at least two places the river was temporarily dammed up by slides from both slopes meeting in the stream bed, but none of these dams was of noteworthy size.

On the ridge east of the Gualala Valley, the ranches of A. and Chas. Lancaster were examined and found to have suffered less damage than Casey's. Chimneys were broken, furniture was damaged, and a small slaughter-house collapsed, tho that structure was known to be a weak one to begin with.

Between the two ranches a fissure was found very similar to, tho smaller than, those characteristic of the fault-zone. Its trend was N. 75° E. No marked vertical movement was in evidence, and while the twisted sods and clods along its line clearly indicated a small horizontal movement, this could not be ascertained for lack of definite objects to measure it on.

Plantation House, Sonoma County. — Most of the houses in this place stood the shock well. One cottage which was crost by one of the strongest fault fissures suffered the partial collapse of its underpinning. Had the displacement of the fault not been distributed over a zone 270 feet wide in this locality, the destruction would probably have been much greater. As it was, broken chimneys and windows and slight damage to underpinning were the principal destructive effects within the zone.

Timber Cove, Sonoma County. — Altho this town is fully 1.5 miles west of the fault, the intensity was apparently but little less than at places much closer to it. The underpinning of one dwelling collapsed, all brick and tile chimneys broke off, and household articles and furniture were thrown down with violence.

In the bluffs along the coast and in the numerous rock cuts along the wagon road, the rocks appeared loosened up, many old fissures having opened and left the rock masses in more or less unstable positions. Landslides, in rocky as well as in loose material, have occurred in a great number of places, tho none were at all extensive.

Fort Ross, Sonoma County. — At Fort Ross, 0.75 mile from the fault, the intensity of the shock was probably greater than the actual damage would indicate. The old Russian Church and several other buildings suffered thru collapse of their underpinning, but all in a fair state of repair stood the shock, as did the more recently built dwellings.

The dwelling of Mr. G. W. Call, proprietor of the place, was violently shaken. The table was moved across the floor to the south and furniture generally was thrown to the ground. There was much broken crockery and glassware. The contents of a pantry, consisting of jars of preserved fruit, were nearly all thrown from the shelves. In cleaning up the wreck after the shock, 6 wheelbarrow loads of broken objects were picked up off the floors of the rooms. In Mr. Call's room a high case was thrown across the bed in which he was sleeping.

Mr. Call stated that in his neighborhood hanging lamps were caused to swing in a circle corresponding with the apparent movement of the sun. There were several shocks, quickly following each other; the first was not the strongest. They seemed to increase in force up to the third or fourth and to come from different directions. He judged that there was a strong vertical impulse. Chimney tops were thrown off, some chimneys being shattered to the bottom. Many redwood and pine trees were broken off, some at the ground, being uprooted; but generally broken about halfway up. All loose furni-

ture was turned over, and a few frame buildings set upon unbraced posts were shaken down. The tendency along the fault seemed to be to crowd the two sides together, as a water-pipe in one place had sprung up in a curve out of the ground. The fact that he found no trees broken at a distance of more than a mile from the fault indicates to Mr. Call that the shock was much stronger near the fault than elsewhere.

Mr. Call resided for some years on the South American coast and had experienced the disastrous effects of sea waves consequent upon earthquakes in that region. The moment, therefore, that he felt the shock he turned his attention to the sea, which is in full view of his house. He reports that it was perfectly still during the shock and afterwards.

South of Fort Ross, at Doda's ranch, a large barn about 150 feet west of the fault was found leaning to one side on the verge of collapse. Several of the dwellings and other smaller houses had slipt from their underpinning. All the chimneys had been broken off or destroyed; household articles and furniture had been thrown down, but no window glass had been shattered or even cracked.

Mr. Doda's daughter stated that she was standing in the kitchen at the time of the shock, and was lifted vertically from the floor more than once, in each case alighting on her feet. A ranch hand who was out-of-doors at the time stated that he saw the water-tank thrown vertically upward about 5 feet and then fall in ruins.

In the forest between Plantation House and Fort Ross innumerable trees, many of them redwoods (*Sequoia sempervirens*) of considerable size, had broken off some distance from the ground (plate 69A, B), or had split lengthwise from the roots up. Some were uprooted altogether, as if by a hurricane. No particular preponderance in direction of throw was noted. Trees on the line of the fault were as a rule split vertically and more or less twisted. In some cases the butts had actually been sheared. A fine instance of this may be seen on the stage road 150 feet east of Plantation House.

At Seaview, a post-office on the summit of the ridge overlooking Fort Ross and probably 1.5 miles from the fault, the shock is described by Mr. Morgan, the occupant of the only house there, as very violent. In a room with two beds, one moved across the room to the south, the other was lifted from the floor. The chimney was thrown to the north.

On the wagon road from Seaview to Cazadero, the steep bank of the road-cuts, generally of disintegrated sandstone, had in numerous places slid down upon the road.

At Cazadero the shock was severe and chimneys were generally thrown, but no buildings were wrecked, all the structures being of wood. Mr. H. L. Conley, of this place, stated that according to his observation the shock was from north to south, chimneys falling south. In a store the chief walls of which trend north and south, hardly any damage was caused. Some pictures hanging against walls were turned around so as to face the walls. There seemed to be two maxima, the second being the strongest.

BETWEEN THE COAST AND THE UPPER RUSSIAN RIVER.

For the territory between the coast and the upper Russian River Valley, we have the following notes by Dr. H. W. Fairbanks:

At Geyserville the shock was much less severe than at Santa Rosa. Chimneys and portions of brick walls were thrown down. The shock at Skaggs Springs, 8 miles west of Geyserville, was not severe. Chimneys were knocked down, but no other damage was done. On the summit of the ridge, 6 miles west of Skaggs Springs, chimneys and crockery were broken, the shock apparently being fully as severe as at Skaggs. There are no other dwellers along the Stewart's Point road until within 2 miles of the Rift, where the shock was of course severe.

Another section is that across the country from Point Arena to Cloverdale. At Booneville, in Anderson Valley, there is quite a settlement. About half the chimneys were down, and Dr. Diddle, apparently the best-informed man in the town, thinks that the shock was

A. Bell and Kinslow building, Healdsburg. Per J. C. B.

B. Odd Fellows' Hall, Healdsburg. Per J. C. B.

somewhat more severe than at Ukiah. Booneville is a little more than halfway from Point Arena to Ukiah. Ten miles southeast of Booneville on the Cloverdale road, a point a little nearer the Russian River Valley than Booneville, no damage to speak of was done, one chimney being slightly cracked. Sixteen miles southeast of Booneville, a little more than halfway between that place and Cloverdale, milk was thrown out of pans and houses badly shaken. At a house a half mile away cream upon milk pans was not broken. On the mountain 5 miles west of Cloverdale there was no damage done. Two miles west of Cloverdale about half the chimneys were broken. The town itself does not seem to have suffered more than the average place along the road. Most of the chimneys were merely cracked and not thrown down.

While there seems to have been great variation in the intensity of the shock in the sections traversed, it is not clear that there was any increase in the intensity of the shock in the direction of the Russian River Valley at points between it and the coast.

Supplementary to these notes by Mr. Fairbanks, Mr. John L. Prather, of Philo, reports that at that place chimneys were thrown down and broken off above the roof, and in some cases turned quarter way round, clockwise. Glassware and crockery were generally broken and much damage was done in stores and farmhouses.

HEALDSBURG TO WILLETS.

Healdsburg, Sonoma County. Population 1,870. (R. S. Holway.) — This place comes next to Santa Rosa in the extent of damage done to towns in Sonoma County. The shock was definitely less severe, however. The new 3-story brick building of the Odd Fellows Society is a total wreck, as are several other buildings, but many brick structures stood the shock without serious damage. The cemetery is on a low hill similar to that at Santa Rosa, and as at the latter place not over half the monuments fell. Of 35 square monuments of the same class, the direction of fall was as follows: north, 10; south, 11; east, 10; west, 3; southwest, 1.

Along the bottom-land of the Russian River, cracks from an inch to a foot in width opened at several places.

(H. R. Bull.) — The direction of the earthquake at Healdsburg seemed to be from north to south during the early stage of the disturbance. Following this was a decided pause attended by a quivering motion; then followed a vertical movement attended by a great rumbling noise like thunder; lastly, the distinct oscillatory movement which continued thruout.

A piano with its back close against the north wall was shifted 2 feet almost directly toward the south. It was evidently lifted and rolled simultaneously, since the baseboard of the piano was thrust out upon the floor ahead of the piano. A clock on a south wall was thrown 5 feet to the north, while a clock on a north wall was thrown to the south. Plastering on walls extending north and south was badly broken and scattered, while that of the ceiling and the walls extending east and west was only slightly injured. One chimney was hurled toward the east, another toward the south. North and south walls of a brick dwelling 40 feet north of the frame building above described were thrown toward the south. Furniture in this building was shifted also in a similar manner. Residents generally agree as to the general movement being from north to south.

Fissures in the creek bed near the town are in evidence. Water was thrown out and continued to flow for several hours, at first with some considerable force; then it gradually diminished and finally disappeared. Brick buildings were generally injured and in some instances thrown down. (Plate 70A, B.) Many brick walls facing east and west were buckled either in or out, because of the movement from north to south of the north and south walls. Chimneys generally fell north or south. In some cases the oscillatory motion caused chimneys which had withstood the north and south wave to fall in other directions.

(George Madeira.) In the bed-room a heavy walnut and marble composite bureau, mounted on rollers and weighing 400 pounds, was moved toward the center of the room by the first wave motion, which was north to south. It then turned so that the large mirror surmounting it was due north. In the house are three chimneys built close together. One chimney above the roof fell to the south; but beneath the roof one fell to the south, one to the north, and one to the east, on the ceilings of the back parlor, dining-room, and sitting-room respectively. A large pier glass 8 feet high, with a very heavy marble base, was turned northward. There were two maxima in the shock and the second was the more violent. The first was from north to south and the second from east to west. Not a building escaped damage to some extent, whether made of wood, brick, or stone. There were five brick buildings destroyed. Mr. Madeira estimates the loss at between $200,000 and $300,000. Along the creek and river bottoms the earth was fissured and water was forced up which, in some instances, flooded the orchards.

Alexander Valley to Mt. St. Helena (R. S. Holway). — This trip was made in order to cross the line of the fault described by Mr. V. Osmont[1] on the southwest slope of the mountain. No sign of recent movement was seen, however, and no reports of cracks or landslides were obtained. There are few houses from which to obtain reports. Some chimneys fell as far as Kellogg at the foot of the mountain. At Nays — elevation about 1,500 feet — and at the toll-house southeast of the summit — elevation about 2,300 feet — a severe shock was reported, but nothing was shaken down. In climbing the last 2,000 feet to the summit, large boulders were frequently seen balanced on points and yet not overturned by the shock. The intensity decreased from IX at Healdsburg to about VI on top of the mountain.

Alexander Valley is part of the Russian River Valley lying east of Lytton Springs. The main bridge across the Russian River was wrecked, the trestle-work part going down. The bridge was old and was to have been rebuilt this year. At the east end of the bridge cracks cross the road, northwest to southeast, parallel to the river bank. These cracks appear at intervals northwesterly, at least as far as the ranch of Rev. E. B. Ware, about a mile up the river. The cracks vary from a few inches to over a foot in width, and are sometimes 200 to 300 feet long, roughly parallel to the river. Mr. Ware states that the shock threw the river water upon the sandbars to such an extent that he found fish there during the day. Other cracks are reported a mile or two northward. Subsidence frequently occurs where the cracks are near the bank.

Cracks in the Russian River Flood-plain (R. S. Holway). — Cracks have been observed at intervals in the alluvial banks of the Russian River from near its mouth to Alexander Valley, 5 or 6 miles northeast of Healdsburg. These cracks are sometimes 100 yards in length and from a few inches to 2 feet in width. Sometimes near the bank there will be a deep fault 5 to 6 feet in width and 100 feet long, as shown in the photograph of the crack at Monte Rio. The direction of the cracks is usually parallel to the bank of the river or the bank of some small tributary. At Duncan Mills the cracks ran north and south above the bridge and nearly east and west just below the bend of the river. At Monte Rio they are east and west. In Alexander Valley they run north and south, while a mile or two below some are found nearly east and west running up a small tributary.

Maacama Slide, 6 miles easterly from Healdsburg (R. S. Holway). — This slide is on the north side of a ridge that runs in an easterly direction and that is at this point from 225 to 300 feet above the bed of Maacama Creek, which runs along the foot of the north slope. Mr. Hugh Simpson, whose house is just beyond the foot of the slide, states that the entire slide took place at the instant of the earthquake. The slide is about 0.125 mile wide at the top and about 0.5 mile long. The rock is a very light, porous, volcanic

[1] Bull. Dept. Geol., Univ. Cal., vol. 4, No. 3.

tuff and seems to be free from water. A slicken-sided wall on the east shows a very smooth surface in spite of the soft rock. Striæ near the top run N. 13° W. with a pitch of about 24°. The slide seems to have taken off some of the top of the ridge; that is, it started a few feet down the south slope of the ridge, cut its way thru a fir forest and dammed Maacama Creek with rocks and trees. Either two successive slides occurred or else the upper part of the moving mass was arrested part way down, for a bank with the vegetation of the top rests across the slide about one-third of the way down. (See plate 124A, B.)

This slide was subsequently visited by Mr. G. K. Gilbert, who contributes the following supplementary note:

At Maacama schoolhouse, I saw the large landslide described by Professor Holway. The rocks involved are in layers, with a dip of about 30° in the direction of the slide. It is therefore probable that the slide was partly determined by the dip, tho it seems to have been further determined by the erosion of the valley of Maacama Creek. The shock at that point was notably strong. A young man living close by told me that he was watering two horses at the time, and kept his feet only by holding on to a pump. Both horses were thrown down. The house of Mr. Stimson was thrown from the pegs on which it stood, and all brick chimneys in the neighborhood were broken. He and others mentioned numerous cracks in the bottom lands a mile to the north, and especially in the bottom lands of the Russian River at its neighboring large bend.

Geyserville, Sonoma County (R. S. Holway). — Shock reported north and south and northwest and southeast. Several brick buildings were badly cracked and tops of fire walls thrown down. The northwest wall of a butcher shop (brick) was thrown out against an adjoining frame building, which saved the brick building from an entire fall. Half or more of the chimneys were reported down. Goods were commonly thrown from shelving in stores. The cemetery 1.5 miles northwest in the low hills was not disturbed. The bridge across the Russian River at this point was unhurt. The town is on the west side of the river, on alluvial terraces.

Cloverdale, Sonoma County (R. S. Holway). — The upper walls of a brick building nearly opposite the United States Hotel were cracked so as to necessitate partial rebuilding. A 2-story brick building on First and West streets was unhurt except for cracked plastering. The shock was reported north and south; goods were thrown north and south from the east and west walls. In a 1-story brick building at Broad and West streets goods were thrown from the wall facing north. In the grocery opposite the United States Hotel goods were thrown mostly from the wall facing south. The inspector reports that he has condemned four-fifths of the chimneys, but most estimates agree that not over one-fourth fell. Mr. Scott reports that he went out-of-doors during the shock and that distinct waves in the ground could be seen moving from the west toward the east. The cemetery is on a knoll on the bank of Russian River, and suffered no damage except the fall of a vase from the top of a tall monument. This fell to the north.

(M. C. Baer.) On or about $9^h 30^m$ P. M., April 11, a slight shock (class III) was felt. The general direction seemed to be east and west and to have a trembling motion. The next shock came at $5^h 13^m$ A. M. on April 18, and was of about class VIII. The motion was at first oscillatory, but seemed to end up in a series of jerks. There did not seem to be any general direction. All chimneys were cracked; many windows were broken, and many brick chimneys and buildings were shaken down. The bricks of a chimney from a building about 30 feet high were thrown southward about 70 feet. Generally the chimneys seemed to have shifted or fallen southward, but in some cases they have tended to go in other directions. Many telephone wires were broken. In most cases water was spilt from water-tanks on all sides. It is reported that the water of several streams was partially thrown upon the banks. No cracks in the earth's surface have been reported.

Ukiah, Mendocino County. Population, 2,000. (R. S. Holway.) — A brick building owned by Mrs. White was so badly damaged that it is being taken down. The north fire-wall of the McGlashan Building was thrown down and the engine house is reported unsafe. Mr. Cunningham, inspector of chimneys, reports some 30 to 40 actually down, but probably one-fourth of all chimneys condemned. Sexton Rogers reports no damage in the cemetery. The State Asylum for the Insane, a large brick building, is east of the river and some 2 miles away. The gables fell out, coping and ornamental stones fell from walls, and chimneys fell generally west or east. In one case, where a chimney was braced by an east and west rod, the washer was pulled thru into the flue, but the chimney remained standing. At Vichy Springs a greatly increased flow of water is reported. The water was milky for a few days. Increased temperature was reported, but no thermometer was used to determine this.

(Geo. McGowan.)—The town is partly on bottom-land and partly on a bench slightly above the bottom. There is no rock near the surface and none of the ordinary wells go to rock, but pass thru washt gravel and clay. Ukiah Valley is approximately 12 miles long, and 2.5 miles wide, lying about north-northwest and south-southeast, and surrounded by mountains. Russian River enters at the north end of the valley. At this place it is at the extreme east side and continues near the east side to its exit at the south end. The greater part of the valley floor is alluvial fill. It is nearly level except for a depression toward the south to correspond with the grade of the river. Ukiah is a little to the west of the center line of the valley and about 4 miles from the north end. There are several deep canyons at right angles to the valley in the bordering mountains.

In the town a 2-story brick building, rather flimsily built, the front being set on pillars, was canted about 6 inches to the south, breaking most of the plate glass in the front. It struck against a 2-story brick building just completed, also set on pillars, and the latter was set over nearly a foot and the walls badly cracked. The greater part of a long fire-wall on the north side of a 2-story brick building fell and an inner wall that served as the casing of a stairway was badly cracked. A large number of chimneys were dislocated and some were thrown down. Some of our well-built structures suffered. Quite a number of houses had the plastering more or less cracked. The railroad lost a large water-tank which was thrown down and demolished, tho a large oil-tank near by appears to be uninjured. The shock caused an old sheet-iron tank full of water to break loose at numerous points around the bottom and lose its contents in short order. Of two pendulum clocks one was stopt. Chimneys and loose objects were thrown to the north and south, some one way and some the other, and some chimneys that were not thrown were dislocated and turned partly around, in a direction opposite the apparent motion of the sun. The electric-light bulb hanging over my bed swung first back and forth, then changed to an ellipse and finally almost to a circle. There were two principal maxima, of which the first was the stronger. The first movement was north-northwest and south-southeast and this was succeeded by a twisting motion.

Mr. S. D. Townley, in charge of the International Latitude Observatory, 1 mile south of Ukiah, reports:

Many chimneys were thrown down from 2-story buildings, and also from some cottages. One new brick store building just nearing completion was so badly cracked and thrown out of plumb that it is necessary to tear it down, and several other brick buildings were damaged to a greater or less extent. The particulars are given in the Ukiah *Press* for April 27. A rough estimate of the number of chimneys in town would be 1,000. P. B. Westerman, teacher in the Ukiah High School, reports that 120 chimneys fell, most of them either to the north or south. At the Asylum on the eastern side of the valley, chimneys fell to the east or west. Cemetery monuments were not overthrown. One chimney on a house 200 yards southeast of the Observatory was badly cracked.

At the Latitude Station no damage whatever was done, altho the shaking was the most severe ever experienced by the writer. Dishes rattled, milk was spilt from pans little

more than half full, and fowls and other domestic animals were very much perturbed. There was a series of shocks, and reliable estimates of their duration vary from 20 seconds to 1 minute. The general direction seemed to be from southwest toward northeast, but others report a different direction. The Ukiah Valley is surrounded by mountains of considerable altitude, and it is probable that some of the shocks felt were reflected from the mountains. Hence it is that the earthquake is generally spoken of as a "twister."

The Observatory clock was not stopt, but it lost 6 seconds during the disturbance, which is equivalent to being stopt for that length of time and then set going again. The Observatory roof is built in two sections, which roll upon horizontal tracks, east and west, giving an opening of about 1.3 meters for observation. When closed the two parts are fastened together by means of a hook and eye such as are used on screen doors. The hook rests in a horizontal position and the bend of the hook in a meridian plane. The effect of the earthquake was to unfasten this hook and open the roof to the width of about 20 centimeters, my recollection being that the eastern half was moved about twice as far as the western. The pier upon which the zenith telescope rests was apparently not damaged, but the telescope was thrown considerably out of adjustment. It was out about 15 seconds of arc in azimuth and the vertical axis was out in both directions, but not much more than sometimes results from extreme changes in temperature.

The first series of shocks was followed by three lighter shocks and the observed data for each are as follows:

Pacific Standard Time.	Duration about.	Direction.	Intensity.
Apr. 18^d 5^h 13^m —^{s} A. M.	40^s	SW. to NE.	Severe
18 10 4 39 A. M.	10	SW. to NE.	Medium
18 11 36 0 A. M.	30	SW. to NE.	Light
20 12 30 53 A. M.	—	——	Very slight

The times are correct within 2 or 3 seconds.

I was in the observatory at the time of the second series of shocks, 10^h 4^m, and perceived the effect of the movement in the striding level (east and west) of the zenith telescope. The bubble oscillated over about 2 divisions of the level. The value of one division is 2.2″, and as the distance between the east and west leveling screws of the instrument is about 42 cm., the disturbance produced in the bubble was equivalent to the effect of raising and lowering one of the leveling screws by 0.0005 centimeter. This shock was felt very distinctly and it is probable that the north and south component of the motion was much greater than the east and west component. The fourth shock was not felt at all. It was detected during the progress of latitude observations, by a movement of the bubbles of the latitude levels. The oscillation (north and south) was about one-half of one division, and the value of one division is 1 inch.

My estimate of the intensities for the four shocks given above would be, respectively, VII, IV, III, I. The Observatory is about a mile south of the city of Ukiah, and it seems certain that the earthquake was more severe in Ukiah than at the Observatory. The intensity of the first shock at Ukiah would certainly not be less than VIII, possibly IX.

The direction of all shocks was southwest to northeast, according to bodily impression.

Willets, Mendocino County (R. S. Holway). — Brick chimneys were quite generally wrecked. The Buckner Hotel was completely demolished. One wall fell at the time of the shock, killing Mr. Taylor, the proprietor. The building finally fell at 10^h 20^m A. M. The structure was largely frame, with some brick veneer. The stores of the Irvine Muir Company were badly wrecked. Fire-walls fell; plaster, shelving, and goods were thrown to the floor. Brick walls fell in several other stores, and frame buildings were in some cases thrown from their foundations. Small cracks across some of the streets were reported, but they are not now visible. All brick buildings were damaged to some extent. A tank 2 or 3 miles to the east threw the water out on the northwest and southeast. Colonel La Motte, at the spawning station 5 miles north of Willets, stated that the water of a pool 8 to 12 feet in diameter and 2 feet deep splashed out on the south and southeast, wetting the pickets to a height of 18 inches. It did not splash out in any other

direction. The valley is an old lake bed with ground water within 3 to 4 feet of the surface in April. (See plate 73B.)

At Hemlock, 14 miles east of Ukiah, the shock, according to a report by Mr. C. D. L. Bowen, had two maxima, the second being the stronger. A rotary motion was felt, but no damage was done.

CLEAR LAKE DISTRICT.

For the Clear Lake district to the east of the Upper Russian River Valley, the following notes are from a report by Mr. C. E. Weaver:

Hopland to Lakeport. — Nothing of importance was observed along the road from Hopland to Highland Springs. At the latter place one chimney fell. No cracks nor fissures could be seen. From Highland Springs to Lakeport no cracks were seen, and upon inquiry none were reported. The damage to buildings was slight; only a few chimneys were thrown down.

At Lakeport several brick buildings and one frame building were partly destroyed. A brick building was completely destroyed and most of the chimneys were thrown down. Many chimneys not actually thrown were twisted, and in every case the direction of the rotation was clockwise. All 6 chimneys of the high school building were twisted thru an angle of about 20°. Clocks in general stopt. No fissures nor cracks are reported or were found. The town is built on alluvium.

Upper Lake. — The intensity of the shock is said to have been greater at Upper Lake than at Lakeport. There are, however, no brick buildings there, and only chimneys went down. No cracks nor fissures were formed. This town is also on alluvium.

Laurel Dell. — A crack having been reported at Blue Lake, near Laurel Dell, Mr. Weaver visited the place, but found only a minor slide on the roadside. At Laurel Dell and Blue Lake Hotel chimneys fell. The first story of Laurel Dell Hotel, built of stone, was not affected. No cracks nor fissures were seen or reported between Upper Lake and Lakeport.

Lakeport to Lower Lake. — Between Lakeport and Kelseyville, a distance of 9 miles, a few chimneys were down along the road. Houses are few, however. At Kelseyville, on a wide alluvial flat, brick buildings were somewhat damaged, and chimneys generally were down. The shock was reported to be of about the same severity as at Lakeport. The shock was described by residents as having had first a north to south motion, then east to west, then a twist. One mile south of Kelseyville and half a mile to the west, at the place of Mr. McLaughlin on the Lower Lake county road, a crack was found in the alluvium out of which gas escaped, burning upon ignition. About one mile north are gas wells in the same kind of rock, the gas being obtained by boring to a depth of 165 feet.

About 3.75 miles south of Kelseyville on the road to Lower Lake, at the ranch of Mr. M. E. D. Bates, is a crack varying in width from 1 to 6 inches. It crosses the road about 200 feet below the house. At the right of the road going south it crosses the creek and can be seen no further. At the left of the road it passes up the hill toward Uncle Sam Mountain for about a mile, but is not continuous. Near the road two small trees standing on the crack have been partly uprooted and a fence post has been thrown out entirely. The rock thru which the crack passes is alluvium and a loose, unconsolidated conglomerate. It apparently does not pass thru the hard Franciscan rocks. In places there are as many as 10 parallel cracks, separated by intervals of 5 to 10 feet, which could be traced for only short distances. On the right side of the road, about 100 feet south of the cracks, stands a schoolhouse. It has been slightly tilted to the south. The chimney, made of terra cotta, is bent to the south. The chimneys on the house of Mr. Bates fell.

On the side of Mount Konocti, several large loose boulders were caused to roll down, but no landslides nor cracks were observed.

Cache Creek Canyon. — On Sunday, May 1, a large slide occurred on the side of Cache Creek Canyon. Mr. Weaver visited this and reports that the slide occurred about 4 miles below the junction of the north and south branches of Cache Creek. The creek here flows thru a canyon not more than 1,000 feet wide, with steep walls on each side. At the point where the slide occurred, the creek makes a bend. The rock which slid is a red sandstone. The distance from the creek to the point where the slide began is about 500 feet. The width of the slide is about 300 feet. It occurred on the south side of the canyon and dammed up the latter to a height of 90 feet. The water rose to that level and one week later, May 7, the dam broke and allowed the water to escape down the valley. Nearly all the material was carried off by the water.

At the base of the cliff where the slide occurred are several very large springs; it is stated by Mr. Brainard that springs were common at the base before the slide occurred. About 500 feet back from the upper edge of the slide there is another crack, having a width of from 2 to 6 inches. It is about 300 feet long and the mass of rock in front of it appears ready to slip. No other cracks were seen.

At Middleton the shock was not especially severe. The brick hotel was not injured, but some chimneys were down.

At the toll-house on Mount St. Helena no chimneys were down and the shock was not especially severe.

At Oat Hill, at an elevation of 2,000 feet, on a mountain slope facing east, Mr. J. J. Multer reports that no damage was sustained in consequence of the earthquake. The shock comprized two parts, of which the second was the stronger. The direction of movement was northwest and southeast.

Vicinity of Upper Lake. — Charles Mifflin Hammond says:

I live about 4 miles southeast of Upper Lake, in the approximate latitude of 39° 10′ N. and longitude 122° 45′ W., at an elevation above the sea of 1,350 feet, and about 50 feet above the surface of Clear Lake. The house is 45 by 90 feet, well built, and a story and a half high. In it I have a collection of about 70 clocks, of all ages, styles, and makes. These stand on mantelpieces, on shelves, on the floor, on bookcases, and some are hung on the walls. I have no absolutely correct time, but on the morning of April 18, between 5^h 13^m and 5^h 14^m, my wife and I, who were asleep, were awakened by a violent rocking of the house. We jumped to a doorway and stood there for about 2 minutes, the house gradually coming to a state of rest from its violent rocking and swaying, and a roaring noise passing off in a southwest direction. This direction is corroborated by some of the men on the place who were up at the time. They all said that they suddenly heard a noise in the trees as tho a heavy wind was blowing thru them, and that the rumbling past away to the southwest. There was only one maximum and the movement certainly came from the northeast.

I at once made an examination of the house. The southwest room showed the greatest disturbance. From the top of a small bookcase facing west a large china vase was thrown to the floor and smashed. On my desk, facing north, stood a spy-glass 2 feet high, which was tipt over to the southwest. In the southeast corner room, on a mantel facing southwest, a vase of flowers was tipt over to the southwest. Practically every one of my pendulum clocks had stopt, with two notable exceptions. In the southeast corner room, there stands on a small shelf facing northwest a very delicate Empire clock, which a sheet of paper put under one leg will stop. The clock kept on running, as it did thru all of the later earthquakes. In the southwest corner room there is another delicate clock standing on a bookcase facing southeast. This clock causes me a great deal of trouble, as the slightest variation in its level stops it; yet it was going after the main shock.

At 10 o'clock that morning there was another shock, which was not very perceptible, yet it caused the above clock to stop, and also a few others. At 11^h 40^m I happened to be in the house starting the stopt clocks for a second time, when there came a third shock which again caused some of the clocks to stop.

On May 6, at 8^h 10^m P.M., a very violent shock came from almost due east. We were sitting on the piazza, and it came without a second's warning. I judged it to be fully as severe as the one of April 18, but it lasted only about 10 seconds. In the southeast room, from the same mantel, a small wooden clock was thrown out on the floor to the southwest.

In the southwest room the same spy-glass was upset toward the northeast, and from the top of the tall bookcase, from which had before been thrown the china vase, a bronze figure a foot high was precipitated to the southwest. In the hall, on a bookcase facing west, a small wooden clock was tipt over to the east against the wall. At 9 o'clock that evening there was another shock almost as heavy as the first one, but by that time I was too rattled to take much note of it, especially as I had not started the clocks up again. But the next morning I went at them, and found that in some cases the pendulum had been swung out of the wire loop from the escapement. I tried to locate the direction of the quake from the condition of the clocks, but found that they had stopt indiscriminately, without regard to length of pendulum or direction. They have pendulums ranging from a few inches long to several feet. No plaster was cracked in the house, but many pictures were out of line, and the quakes of May 6 broke off two of my chimney tops at the roof line, the southwest corners of both being moved about 0.75 of an inch in that direction.

In the Rossi-Forel scale, I placed the shock of April 18 in class VIII and those of May 6 in class VII. In none of the shocks was any disturbance noticed on the waters of the lake, nor was there evidence of there having been any waves, yet on the 18th a plank connecting my floating boat-house with the bank was found with its outer end in the water, showing that the boat-house had been pulled away from it. This plank ran about east and west. In all of the shocks the house seemed simply to sway backwards and forwards. There appeared to be no up and down movement. In the cellar under the house the milk was thrown from the pans in a northeast and southwest direction.

Bartlett Springs (Mrs. M. E. Clark). — My husband past the night of April 17 at Upper Lake, where the shock was quite severe, but my son, a boy 16 years of age, was on the ranch, 5 miles northwest of Bartlett Springs. The shock was severe enough to stop the clock. He and another boy felt the prolonged tremor and the rocking of the house. They were dressing when the shock occurred. Nothing, however, was reported as having been knocked over, nor was any milk spilt from pans. At our nearest neighbor's, 4 miles northwest of our ranch, nothing was known of the earthquake till it was mentioned to them 3 days after the event, altho a member of the family thought he felt something. At another neighbor's, 5 miles northwest of here, at Horse Mountain, the wife was awakened but not the husband. At Twin Valleys Ranch, a smart shock was felt and the clock was stopt.

Lower Lake (W. C. Goldsmith). — No chimneys were thrown down in the town, but 2 chimney tops fell to the southwest at a point about one mile northeast of the town. Mr. Weaver reports that Lower Lake is on Eocene sandstone, and that the shock was much less than at Lakeport or Upper Lake.

Sanhedrin, Lake County (V. L. Frasier). — This place is in a small alluviated valley surrounded by mountains. One shock was felt which was not severe enough to throw chimneys. The motion was from northwest to southeast. Some men in a tunnel in solid rock, 800 feet below the surface, did not feel the shock, and people living on the surrounding mountains report the shock as much lighter than in the valley.

In the district about Knoxville, Mr. Weaver reports that a few chimneys at ranch houses fell, but that no severe damage was occasioned. To the east of the crest of the Coast Ranges, in the latitude thus far considered, observations indicative of the intensity of the shock become more scattering, and people generally attached little importance to their experiences of the morning of April 18.

FORT ROSS TO BODEGA HEAD.

We return now to the coast south of Fort Ross. An examination of the coast between Fort Ross and Bodega Head was made by Prof. J. N. LeConte and Mr. A. C. Wright. The portion of their report dealing with the distribution of intensity follows:

From Fort Ross the line of the earthquake fissure was followed south to the point where it passes into the sea. From this point we followed the beach for 8 miles. Several slides were seen about 3 miles south of the Fort. One of these was of great size, being between

300 and 400 feet in height. These are evidently old slides, and the amount of material brought down by the recent earthquake, though large, is insignificant compared with the size of the scar. At Rools Landing the beach was abandoned, and the wagon road was followed to Davis Mill at the mouth of the Russian River. The earthquake here had caused several thousand dollars' damage to trestles on the logging railroads. No buildings were moved on their foundations, only chimneys being thrown down.

From this point the road along the bench above the sea was followed 12 miles to Bodega Bay (see map No. 4). The country is sparsely settled. Only three or four houses were past, and these were uninjured except for broken chimneys. Near Bodega Head the bridge over Salmon Creek was somewhat twisted. Just beyond this a good-sized hotel, previously used as a summer resort, was badly wrecked by the earthquake. It was moved on its foundations, and rendered unfit for habitation. This building was close to the sand-dunes and probably rested on sandy deposits. The barn was completely wrecked. A few hundred yards beyond this a small mud-flat extends from the sea up to the road. Curious mounds of mud, shaped like truncated cones, were thrown up by the earthquake. Subsequent examination showed that the line of the earthquake fissure must have past near this spot.

Duncan's Mills (J. Parmeter). — On the Russian River, when fisherman tried to seine fish after the earthquake of April 18, their nets were torn to pieces by snags, etc., where there had formerly been no obstruction. Large trees that had been buried in the bed of the river were lifted up by the convulsion, while other trees vanished that had been in sight. Low places in the river bed were made high and *vice versa.*

The bottom of the river appears to have dropt 2 feet all along by Duncan's Mills for 2 miles; and at the mouth of the river, where there used to be water 12 or 14 feet deep, there is now only 2 feet, and a riffle till boats can hardly cross, for a length of almost a mile. For over a mile there is now a strong current, where there used to be quiet water with very little current. A man who was by the river, near Monte Rio, when the earthquake occurred, told the Parmeters that he saw the muddy bottom of the river rise to the surface, and the water ran off over the banks. The bottom was the highest where the water had been 8 or 10 feet deep; then it settled back. A road and fence moved 10 feet. On the other side of Russian River from Duncan's Mills, 200 or 250 feet back from the stream, the earthquake made many holes thru which black sand and water blew up. Such blow-holes were made all along this river. Between the river and the ruined hotel at Duncan's is an irregular crack about 20 feet wide, 80 feet long, and 1.5 to 4 feet deep, with a blow-hole 4.5 feet wide and 2 feet deep where coarse river gravel came up.

(R. S. Holway.) — One hotel at Duncan's Mills was completely wrecked and other buildings were much damaged. Along the river there were several cracks in the alluvium.

(I. E. Thayer.) — The shake was of great severity on the Russian River at Duncan's Mills, and totally destroyed a large hotel. Several small houses were thrown from their foundations.

TOMALES BAY TO BOLINAS BAY.

By G. K. Gilbert.

The following data upon intensity were gathered, with slight exceptions, between April 26 and May 12, 1906. In their arrangement the order followed is: (1) The line of the fault from south to north; (2) the towns of the Rift belt; (3) the peninsula west of the Rift; (4) routes of travel east of the Rift; and (5) distribution.

Along the Fault. — Mrs. Steele's farm buildings, near the head of Tomales Lagoon, stood in a very narrow fault-sag which was traversed by the fault-trace. At this point the trace consists of a group of cracks 10 to 20 feet broad. The barn, resting partly on the ground traversed by these cracks, was demolished so that, as I saw it, it lay in ruins. The house, standing only a few feet to the east of the fault, was thrown from its underpinning and a wing was partly separated from it.

The buildings of E. R. Strain, 1.5 miles north of Bolinas Lagoon, stand about 20 rods east of the fault-trace, the house being on a hill and the other buildings on sloping alluvium at its base. The house did not leave its brick foundation, but the foundation was cracked. Chimneys were thrown down. The other buildings were thrown from their underpinning, moving eastward. Milking was in progress in the barnyard. Some cows were thrown down, and Mr. Strain himself was thrown to the ground, but rose and grasped a tree, of which he retained hold with much difficulty.

Daniel Bondietti lives 3.5 miles north from the head of the lagoon, and his buildings are about 20 rods east of the main crack. His house was shifted 3 feet toward the fault and his barn moved in the same direction. Men engaged in milking were thrown in a direction away from the fault — that is, to the northeast—and cows were also thrown in this direction.

At a barnyard near Bondietti's, and east of the fault, a milker was thrown to the west — that is, toward the fault.

At Beisler's ranch, a short distance north of Bondietti's, the fault-trace is in two parts, of which the western or main part passes under the barn, and the eastern between the house and the barn. Mr. Beisler was milking a cow at a point within 6 feet of the west branch, and on the southwest side. He was thrown to the southwest, arose, and started to go in the opposite direction, when he saw the crack in the ground; he then turned and was again thrown, but with difficulty reached a fence 10 or 15 feet away before the end of the shock. His house and buildings were strained, but they did not collapse, and their shifting was slight. The greatest shifting was of the main part of his barn, which stood between the branches of the fault and moved about 2 feet to the northwest. A water-tank near the fault was shifted slightly but did not overturn. At both the Bondietti and Beisler ranches the surface of the ground has considerable slope and it is probable that bedrock is not far below the surface.

The buildings of the Dickson ranch, 2.5 miles south of Olema, are about 0.25 mile east of the fault-trace, standing on a hillside presumably on firm ground. They nearly all slid southwest — that is, downhill and toward the fault. The barn, an old building, collapsed.

At the Bloom place, a mile south of Olema, the buildings stand 30 or 40 rods east of the fault, and are on firm ground. The injury to buildings was here comparatively small. A water-pipe by which water was brought from a point on the opposite side of the fault was broken in many places, being at some points pulled apart and at others telescoped. At one place it buckled so as to project several feet above the ground. After being repaired, the pipe was found to be shorter than before, the difference being estimated at about 5 feet. I did not examine the course of the pipe, but from its general direction I infer that it crost the fault obliquely from south to north, and that the shortening was the direct result of the horizontal throw of the fault.

Mr. Payne J. Shafter's place is near the village of Olema. The fault-trace is close to the house and other buildings. These stand on a bed of alluvium which is probably supported by bedrock at a short distance below the surface. In the barnyard men were milking, and were thrown violently to the ground, along with the cattle. The buildings were much damaged. During the earthquake a cow fell into the fault-crack and the earth closed in on her, so that only the tail remained visible. At the time of my visit the tail had disappeared, being eaten by dogs, but there was abundant testimony to substantiate the statement. As the fault-trace in that neighborhood showed no cracks large enough to receive a cow, it would appear that during the production of the fault there was a temporary parting of the walls.

Mr. Skinner's ranch is 0.5 mile west of Olema and on the line of the fault. The trace passes within about 10 feet of the house and within 2 or 3 feet of the dairy, and runs under a portion of a large cow-barn. The house stands southwest of the fault-line, and is on the block which moved northwest. The house itself was shifted northwest with reference

to the ground. (See fig. 22.) A granary standing 100 feet farther west than the house was shifted southward about 3 feet. The movements of the house and granary were thus in nearly opposite directions. The dairy remained on its foundations. The barn was not shifted on the earth block supporting its greater part, but was dragged along over the other block. Movables in the buildings were thrown about with violence; dishes, etc., were broken; but no buildings were destroyed and all were afterward repaired and used. A circular water-tank standing on a trestle about 12 feet high, approximately 100 feet northeast of the fault, was uninjured, and seemed to be absolutely undisturbed. In the barn-yard, which was traversed by the fault, cows were assembled and several men were engaged in milking. Cows and men were all thrown to the ground, the direction of their fall being northeastward and away from the fault. This direction was also downhill.

The road from the Skinner place to Olema crosses a small creek, and near the bridge is a deep pool. Water from this pool was thrown out to the southwest, being carried across the road a total distance of 3 or 4 rods.

Bolinas. — At the south end of the peninsula is a sloping plain carved by the sea when the land stood lower than it now does. Its general form and relations are shown by the contours of the map, fig. 10. This plain originally extended at least as far as the shore of Bolinas Lagoon, but east of Paradise Valley it has been modified by changes associated with the Rift. The line of Paradise Valley, when extended southeastward parallel to the fault-trace, marks approximately the limit of the Rift in that direction, and all the land between it and the fault-trace is broken into blocks which have been diversely faulted and tilted. As some of these blocks retain the smooth upper surface which they received as parts of the plain of marine denudation, their present attitudes serve to express the nature of the dislocations. Two small blocks facing the southern part of Bolinas Lagoon retain approximately their original height, but are tilted at different angles toward the northeast. A third block, too narrow to be caught by the map contours, has dropt 50 feet lower and is tilted at a still higher angle toward the northeast. A fourth and much larger block, itself involving minor dislocations, slopes southward from a point opposite the head of Paradise Valley to the delta of Pine Gulch Creek. The upper part of the village of Bolinas lies in a curving fault-sag among these dislocated blocks, and another portion stands on the delta of Pine Gulch Creek. In the fault-sag, where the ground was much cracked, nearly all the houses were either shifted on their foundations or else thrown from their foundations. There was great destruction of furniture and other breakable articles. In some cases people were thrown from their beds, but none were seriously injured. Three buildings which had stood on stilts along the shore of the lagoon were tipt toward it so that their lower edges came within reach of the tide. Several buildings were so badly injured that they were afterward torn down by their owners instead of being repaired. Just outside the fault-sag, and only a few rods distant, a group of houses stand on higher ground, and these were comparatively uninjured. They were not moved on their foundations, and in one instance the chimneys were not thrown down.

In the northern part of the town, standing on the delta of Pine Gulch Creek, about half the buildings were thrown from their foundations, and here also the destruction was greater on low flat land than on higher ground.

Olema. — The village of Olema is about 0.5 mile east of the fault-trace and at the edge of the Rift belt, the greater part being included within the Rift. The residence of Mr. Pease, standing on alluvium, was shifted south about 2 feet, falling from its supports. It was very badly wracked, and was eventually torn down. A neighboring piece of alluvial land bordering Olema Creek sank about 2 feet. The hotel owned by Mr. Nelson, standing on higher ground, was somewhat wracked but was not shifted. A house next door moved 2.5 feet to the northeast. A house opposite moved 2 feet to the northwest. Another house opposite fell from its supports, moving southwest. A neighboring stable

was wracked so as to lean to the southwest. A church moved 3 feet to the southwest, that direction being downhill. Probably half the houses in the town were not shifted from their foundations. Of two bridges over Olema Creek, one was shaken to pieces. A lady in the hotel was thrown from her bed by the shock.

Point Reyes Station. — The village at the railroad station of Point Reyes is about 0.5 mile northeast of the fault-trace, and stands on a low bench of apparently firm ground. It is probably just outside the Rift belt. The schoolhouse, a 2-story building standing on a brick foundation wall, was shifted 2.5 feet to the south. A stone building used as a store was thrown down, the walls falling toward the southeast. The hotel barn was shifted 20 inches toward the south and a few other buildings were shifted, the distances, so far as observed, being less. Brick chimneys were generally thrown down. A large shed was wrecked. In all buildings furniture was shifted, objects on shelves were thrown down, dishes were broken, etc. An engine and three cars standing on the track were overturned toward the southwest. A long wood-pile was thrown down toward the southwest.

Inverness. — Inverness is a village of summer residences on and near the southwest shore of Tomales Bay. The upland of the peninsula there closely approaches the bay. The village occupies two narrow valleys normal to the shore, and a mesa between them. Its site is within the Rift, and both valleys and mesa were traversed by many cracks, of which some had the character of branch faults. All the houses were of wood. About half of them were shifted on their foundations. To a certain extent the direction of shifting was determined by the slopes of the ground, the houses moving downhill; but where that factor did not control, the movement was toward the west or southwest. In one instance I noted a southwestward movement of several feet uphill. A few houses in the southern or "first valley" near the beach were demolished, or so badly injured as to be torn down. Several houses on the mesa were so badly injured as to require practical reconstruction. As the most serious injury was to houses thrown from their foundations, it is probable that the jar of falling was an important factor. It is related that a number of persons were thrown violently from their beds, but there were no serious personal injuries. Of a series of bath-houses standing on the beach, some remained unmoved; others were tilted because of the yielding of their slender supports; and one was turned over on its side without the breaking of the pins on which it stood. It fell to the northwest. A water-pipe following an east-west (or northeast-southwest) road on the mesa, and buried about 1 foot, was buckled at two points so as to be lifted above the ground. I saw no earth-cracks near these points. (See plate 71A.)

The phenomena connected with five water-tanks seem worthy of special mention, because the simplicity and symmetry of the structures were such that the directions of displacement must represent closely directions of earth movement. A large tank containing water for the village supply stood on the mesa about 0.5 mile from the shore of the bay, its foundation rising a little above the ground. It was thrown in a direction almost due west and completely demolished, the planks and staves constituting its sides and bottom being strewn over a space of 50 feet. (Plate 72A.) The other four tanks were situated along the base of the hill between Inverness and the head of the bay, and held water for sprinkling the road. Each one stood on a square pedestal of braced timbers about 10 feet high. The tank nearest Inverness fell to the west, its pedestal yielding and being crusht. (Plate 72B.) The next fell to the southwest, and tank and pedestal were both crusht. The third was shifted 4.5 feet westward on its pedestal, both tank and pedestal remaining uninjured. The pedestal of the fourth stood unchanged, and the tank was thrown from it toward the west-northwest, being overturned as it fell. (Plate 71B.)

Inverness to Point Reyes Light-house.—For the first 2 miles of travel, covering a right-line distance of about 1.5 miles, road-cracks were numerous and often large. There were also numerous small falls of earth from the road cliffs. Beyond that point there was a rapid falling off of such evidence, and tho road-cracks were frequently seen they were all

A. Buckled water-pipe, Inverness. G. K. G.

B. Wrecked water-tank, near Inverness. G. K. G.

A. Ruin of Inverness reservoir, a circular tank which before earthquake stood in shed. Parts of shed also lie in foreground, about 50 feet from original position. G. K. G.

B. Wrecked water-tank near Inverness. G. K. G.

small. In the neighborhood of Limantour Bay (indicated on some maps as Drake's Estero) there are a number of ranches. Most of these showed broken chimneys; but at a ranch west of the head of the bay 2 brick chimneys stood uninjured. At Point Reyes Post-office, the main residence building was thrown from its foundation of props and shifted 2 feet westward, being badly wrecked. Other buildings of the same group were not shifted, and 2 water-tanks on high frames seemed to be uninjured. At Mr. Claussen's ranch, south of the Post-office, 2 buildings were shifted a few inches to the south, that direction not being determined by their structure but being diagonal to their sides. The chimneys were thrown down, plastering cracked, furniture shifted, and many dishes broken. A picture was reversed so as to hang face to the wall. Mr. Claussen, being out-of-doors at the time, was thrown down. Some cows were also thrown down.

At the U. S. Life Saving Station, on the coast 3 or 4 miles from the light-house, brick chimneys were broken but not thrown down, furniture was moved, dishes were broken, and the filled ground about the house settled several inches. A mast standing in the sand was said to have been heaved up several feet, but its position had been restored before my visit. My informant said that he was standing when the shock came, and sat down to avoid falling.

At Point Reyes Light-house the heavy mechanism controlling the light was shifted several inches on its base. A lens "jumped" from its ways. It was so held in place by dowel pins that its movement required a lift of about 2 inches. The only injury to buildings was from the cracking of chimneys. Wooden tanks with water were not shifted. One of the light-house keepers stated that after the shock he lookt from the window of his room, which commanded a portion of the sea near the beach, and saw the water "boiling," but there was no change of the nature of a wave.

Sunshine Ranch and Vicinity. — I drove to the summit of the ridge southwest of the head of Tomales Bay, finding abundant and strong road-cracks all the way to the crest, which is about 1.5 miles from the fault-trace. There were also a number of landslides in this region, and a considerable number of trees were broken or uprooted. There were few houses. The only ranch visited, known as the Sunshine Ranch, and occupied by Mr. Silver, suffered as severely as the houses of Inverness and Bolinas. The house moved southwest 3 feet and was badly wracked. The dairy was thrown from its foundation and wrecked beyond repair. The barn, a large building, fell northward downhill and collapsed.

Bear Valley. — I drove from Skinner's ranch southwestward thru a pass in the upland, covering two-thirds of the distance to the coast, and reaching a point about 3.5 miles in a direct line from the fault. The most striking evidence of violence was shown by the trees. A few were thrown down, including oaks and spruces; branches were broken from others and some spruces had lost their tops. Most of these phenomena were seen within 0.5 mile of the fault. In the same region are a few summer cottages, which sustained little injury, only the fall of chimneys being noted. The club-house of the Country Club, situated about 1 mile from the fault, lost chimneys but was not shifted. One of its barns was wrecked, falling downhill in a southerly direction. In this region I saw only a few cracks other than road-cracks, and the road-cracks were unimportant.

Seven Lakes. — Crossing the main divide of the peninsula near the head of Pine Gulch Creek, I followed a road to the vicinity of the coast, a district known as Seven Lakes. As the trip was made 5 months after the earthquake, the evidence from road-cracks had disappeared. There were a few landslides, and a number of cracks already mentioned (page 75) testified to movements of large blocks of ground; but I think these were due to a peculiarly sensitive condition of the country rather than to the violence of the shock. At 2 ranch-houses not far from the ocean, chimneys were broken but buildings were not shifted. A few dishes were thrown down, but otherwise there was no injury to movables or houses.

West of Bolinas. — Driving 2 miles west of Bolinas, and looking at buildings from the road, I saw very little evidence of injury. At a distance of about 0.5 mile from the fault a chimney was broken at the roof, but not lower down.

North of Point Reyes Station. — I drove a few miles north and east from the station, over a high terrace separating the upland from the bay at the east. The injury to buildings was found to be much less there than at the station, and not all chimneys were thrown down. A large barn was seen to lean as tho some of its props had given out; two water-tanks were wrecked. A few cracks were seen in the ground, but they were much smaller and less numerous than at a similar distance on the opposite side of the fault.

Sausalito to Point Reyes Station. — Observation was made only from the car-window. The towns from Sausalito to Fairfax showed no damage more serious than the loss of a portion of the chimneys. The same remark applies to buildings seen along Papermill Creek as far as Garcia. Beyond Garcia the creek has several reaches of alluvial bottom, and some of these were so badly shaken that the railway embankments and trestles had to be repaired. Railway traffic to Point Reyes was interrupted for about 10 days.

Ross to Bolinas. — This road was driven over 8 days after the earthquake. In the village of Ross houses were not shifted. The principal injury is to brick chimneys, of which probably more than one-half fell. A group of stone buildings on a hill lost heavy stone chimneys, and there was injury to a tower. Some stone fences on alluvial ground were in part thrown down. These fences were of undrest stone, loosely piled. In San Anselmo most of the brick chimneys were broken, but other injuries in that town and in Fairfax appear to have been slight. Along the road from Fairfax to Bolinas Ridge, the only evidence of the earthquake consisted of small road-cracks, with occasional stones fallen from the road-cuts. These evidences of moderate disturbance continued down the western slope of Bolinas Ridge to the edge of Bolinas Lagoon. A house standing in the middle of the valley, probably 0.25 mile from the main fault, showed from a distance evidence of considerable disturbance. Its chimneys were broken, the house itself had probably been shifted on its foundations, and one of the outhouses was out of plumb, apparently having slidden downhill toward the northward. The house was not visited, but was merely seen from the road.

The general fact brought out in this drive was that the region about Ross and Fairfax experienced a shock comparable with that at Berkeley, and there was no evidence of high intensity until the fault-trace was closely approached. Landslides were not seen east of the lagoon, and the road-cracks east of the lagoon were not important.

Mill Valley to Bolinas. — At Mill Valley the visible injury was chiefly to chimneys. Extended enquiries were not made; but no reports were heard of destruction to furniture. The houses were not shifted. The buildings at West Point, on the Tamalpais Railway, did not suffer; and I was told that there was no injury from the earthquake at the hotel on the summit of the mountain. From crags on the south slope of Mount Tamalpais, stones were detached and rolled down the slope. The same thing occurred near Willow Camp. From West Point to Willow Camp there are no buildings, road-cracks were small, and no landslides were seen. A few stones fell to the road from the side of the road-cut. A ranch 0.5 mile east of Willow Camp showed no injury to buildings. At Willow Camp all brick chimneys fell, several houses moved a few inches toward the southeast, and dishes were thrown from shelves. A tall house 0.5 mile to the northeast was apparently not disturbed, and retained its brick chimney. Farther up the shore of the lagoon, and nearly opposite Dipsea, some farm buildings seemed to have been so disturbed as to be thrown out of plumb. They were not visited. At Dipsea 2 summer cottages were moved a few inches to the southwest, or were wracked in that direction. The hotel was swayed in the same direction, but the building withstood the shock. The barn, a rather large building, was thrown from its underpinning, falling toward the lagoon.

Distribution. — The variation of intensity with the character of the geologic formation is evident at various localities, but most conspicuously at Bolinas, where the destruction on alluvium at the bottom of the little valley was very much greater than on the hills immediately adjacent. Nevertheless, the data are not sufficiently full for a satisfactory discussion of this phase of the distribution of intensity, and I have therefore tried to make allowance for differences of formation, and in that way obtain a general conception of the distribution of intensity with reference to the fault and the Rift.

The intensity was greatest on the line of the fault, but did not diminish rapidly toward the east and west within the Rift belt. In a general way the intensity was greater in the Rift belt than on either side. On the east it fell off rapidly — almost suddenly — at the limit of the Rift. On the west it fell off gradually, being nearly as high at a distance of 0.5 mile or 0.75 mile from the rift as at the edge of the Rift. In a general way the intensity west of the Rift was greater than at the east. My conception of the distribution on a line normal to the Rift is exprest by the following curve (fig. 50), but this should not be subjected to measurement, as its elements are not definitely quantitative. It is a generalization from data that are heterogeneous and by no means complete.

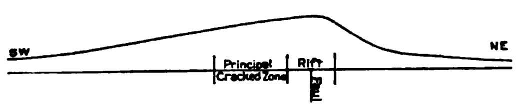


FIG. 50. — Curve illustrating distribution of intensity in relation to fault-trace and Rift. The height of curve above horizontal line represents intensity.

In a general way the distribution of high intensity follows the distribution of bedrock cracks. Inverness, where the injury to structures on firm ground reached a maximum, is traversed by important bedrock cracks, some of which are to be accounted as branches of the main fault. The high ridge west of the main valley, over which the intensity was nearly as great as along the Rift, was also characterized by many important bedrock cracks, and by a general derangement of the underground circulation of water. The district east of the Rift, where the intensity rapidly diminished, was practically exempt from bedrock cracks, and its underground circulation was not disturbed.

Notes by other observers (R. S. Holway). — A bridge about 0.75 mile southeast of Point Reyes (toward San Francisco) went completely down, causing several days' delay to trains. The track had had several horizontal bends of a few inches.

The "fills" across the arms of Tomales Bay generally sank from 2 to 8 feet. The 1,000-yard fill about 2 miles north of Point Reyes Station sank from 6 to 8 feet; as did the next fill, which is some 500 feet long. In one or two instances the pile-supported bridge in the middle of the fill remained at grade. Just above Hamlet a trestle-work which had been filled in settled, leaving the trestle-work some 2 feet above. The bottom of the bay in these arms is usually sand.

At Hamlet quite an extensive landslide has started in the hillside above the track. The railroad cut is in old rock, and the arch of the head of the slide is some 70 feet above the track. The country wagon road has been carried away by the slide for possibly 100 yards.

Miss Margaret Keating, a teacher at Marshall's, just at the close of the earthquake saw two waves coming from the opposite side across the Bay; that is, the length of the wave was parallel to the main Rift. The waves were from 6 to 8 feet high. The waves came nearly to the top of the trestle, and also up to certain willows which she indicated, both points roughly indicating a wave of the height she mentioned.

At Marshall's a hotel and a stable built on the west side of the track and on underpinning, resting in the tidal flat, went easily and gently into the bay. The occupants of the hotel did not realize that the hotel had fallen, but at first thought the water had risen. At the post-office store goods were thrown from the west wall, but scarcely at all from the east.

George H. Covert, of Cypress Grove, about 0.5 mile north of Marshall's, states that on the morning of April 18 he saw a wave 8 to 10 feet high, and white-capped, come broadside on to the east side of the bay immediately after the shock. That is, the wave-crest was parallel to the axis of the bay. The ground has a gentle slope here, and the wave did no harm. Mr. Covert gave a clear, intelligent account, and fully corroborated the testimony of the teacher at Marshall's.

The island in the bay nearly opposite Hamlet was visited, but no sign of the fault was found. Tomales Point, west of the bay, was crost at the "Gum Trees." Small landslides were found on the bay shore on the ocean side of the point at various places. On the peninsula no cracks were found. At one place on the ocean shore a projecting granitic, rocky spur was much crusht and ground in the narrow neck connecting it with the mainland. The spur is about 30 feet high and 50 feet long.

Prof. E. Knowlton gave an account of the damage caused by the earthquake at Bolinas and vicinity in the public press, extracts from which are here quoted:

> Along the main street of Bolinas stand most of the houses, not far from fifty in number and all frame. Of these about two-thirds were heaved, slid, tipt, and shattered into uninhabitable condition. No fatality occurred. As in San Francisco, most of the chimneys came down, but the shock was much more severe in Bolinas than in San Francisco. Along the bay shore were 7 buildings. Of these 6 went over or down. At the Flag Staff Inn the tipping of the house has thrown it so far east into the bay that one may sit along the upper edge of the parlor floor and fish in 4 feet of water along the opposite edge of the same room. The village church was pitched forward and downward, falling 3 feet; pews were torn loose and pitched about, with walls and ceilings cracked and shattered. The large new 2-story building now containing the Post-office, 50 x 30 feet, was swung 5 feet off its concrete foundation at the north end. Back of the Steele place, near the north end of the lagoon, the hillside started eastward toward the lagoon, bulged upward, and cracked into several fissures from 30 to 100 feet long and from 5 to 18 inches wide. The great ocean bluffs along the south and west of the entrance to Bolinas Lagoon, some 165 feet high, crumbled and fell, crashing down upon the ocean beach and reducing the slope of the bluff to half its former angle. The two bluffs along the stage road from the head of the lagoon to the town also broke and fell from 40 to 60 feet, completely blocking the stage road along the lagoon beach.

BETWEEN THE COAST AND SANTA ROSA VALLEY.

Tomales, Marin County. Population 300. (R. S. Holway.) — The Catholic Church, a fine-looking stone building, was completely wrecked (plate 81D), as were the brick bank and saloon, and a stone store building. Several frame buildings were pitched from their foundations and wrecked. A brick chimney on the United States Hotel was pitched north and went over the porch, falling in the street. All chimneys were down. Cracks were reported in the street and near the depot. Just north of the depot there was an extensive landslide along the railroad, which threw one track over the other. (Plate 129A.) In the cemetery 18 square monuments fell north or south, 11 north, 3 south; 3 square monuments fell east or west. No monuments of any size were left standing except 3 heavy and relatively low rectangular stones. In another cemetery, 0.5 mile out of town, 20 monuments fell north and south, and none east or west. Four monuments were left standing. A small spring started in the basement of Mr. Cornett's house, which stands on the hillside near the depot. A stone dwelling 1.5 miles southeast of the town was completely wrecked, killing two people. (Plate 81C.) At Freeman's, 3 miles northeast of Tomales, a large landslide was caused by the shock. (Plate 129B.)

(Mr. Donell.) — At noon, April 17, the plaster fell in a store and broke the show-cases.

Dillon's Beach (R. S. Holway). — Chimneys were thrown from the small cottages, but one chimney on the main building remained standing.

A. Cold-storage plant, Petaluma.

B. Buckner Hotel, Willets. R. S. H.

C. Corner Main and Washington Streets, Petaluma.

Tomales to Petaluma (R. S. Holway). — Route, eastward to corner south of Two Rocks, and then southward to Walker Creek; thence eastward to Petaluma.

The stone house which fell and killed two girls is on this road, less than 2 miles from Tomales. Chimneys are generally down, but there are several exceptions. Between the lagoons (5 to 6 miles south of west from Petaluma) increased flow of spring water is reported. No cracks are reported in the low alluvial land around the lagoons nor in Chileno Valley.

Valley Ford, Sonoma County. Population 300. (R. S. Holway.) — There are only 3 brick buildings in the village. One entire wall of the bank fell; other walls were partially wrecked. The walls of the other two buildings were partially wrecked. A large frame house just west of town shifted from its underpinning and was badly wrecked. General loss of chimneys and minor damage to small buildings resulted from the shock. There are quite a number of cracks in the flat valley-bottom adjacent. A landslide of several hundred yards in length but of very slight movement is found on the side of the valley directly east of town. The slide has moved just enough to make a furrow-like ridge on the lower side and has developed cracks on the upper side. Other small slides occur in the vicinity.

(H. M. LeBaron.)—Valley Ford is about 25 feet above tide water, and there are rocks near the surface in many places. Chimneys and objects were thrown north and south; the motion of the shock was north and south; and no vertical movement was felt. Brick buildings were partially destroyed, and many chimneys were thrown down. The foundations of many wooden buildings were damaged, some foundations giving way entirely. A large, well-built wooden residence of two stories was thrown to the south 3 feet and to the east one foot, and caused to drop down 3 feet.

Bloomfield, Sonoma County. Population 200. (R. S. Holway.) — This village is on the north side of the little valley running eastward from Valley Ford. The 3 brick buildings, two stores and a dwelling, were wrecked. Every chimney but one reported down. Several frame buildings shifted on their foundations. The cemetery is very badly wrecked; about 80 per cent of the larger stones fell. Of square monuments of approximately the same class, the direction of fall was north 11, west 14, south 8, east 0, southeast 1, total of this class, 34.

Bodega, Sonoma County (H. C. McCaughey).—The town is on a hill slope and creek-bottom in a valley surrounded by hills. Chimneys and objects were thrown southerly. Several houses were shifted on their foundations, and all chimneys were thrown. Good frame buildings with strong foundations were not hurt. There are no brick buildings in the place, but a mile from town there is a brick bark-drier. Altho this building is small and the brick work was bound together with iron rods, it was thrown into a heap.

SANTA ROSA.

In the section of the Coast Ranges inland from the coast, between the latitude of Healdsburg and the Bay of San Francisco, Santa Rosa first claims attention. This city, with a population of 6,700, suffered relatively more than any other place in California, except perhaps Sebastopol and Fort Bragg. Prof. R. S. Holway made a study of the effects of the earthquake at Santa Rosa and the surrounding territory, and an excellent report by this observer follows:

Santa Rosa lies on the eastern side of Santa Rosa Valley, which is here some 7 miles wide. The valley floor is a gently sloping alluvial plain with an average elevation of about 150 feet within the city limits, falling with a slight grade to the swampy lands adjacent to the Laguna de Santa Rosa, which runs close to the foot-hills on the west. The elevation at the Sebastopol railway station is but 68 feet above the sea.

Santa Rosa itself is on a low-grade alluvial fan which heads in a narrow gap in the foot-hills bordering the town. This gap connects with a basin of some 40 square miles, which empties its drainage on to the Santa Rosa fan, in a stream that formerly shifted its course over the slopes. Old channels are still to be found in places, altho they are usually filled by the grading for streets and buildings. A bridge formerly crost the main channel on Tenth Street, near Mendocino. The approximate course of this channel is shown for a short distance on the accompanying map, No. 16. The present course of the creek was adopted but recently, according to the testimony of early settlers. The wells in town are shallow, and none were reported that had been sunk thru the alluvial deposits to bedrock. With these physiographic conditions, it will be seen that the alluvial fan upon which the town lies must have been filled nearly to the surface with ground water during the early springtime. The physiography of the vicinity is one of the factors to be considered in discussing the great destruction which was caused in Santa Rosa by the recent earthquake.

The shock of April 18 and the ensuing fire caused a loss of life of 61 identified dead, with at least a dozen "missing," and practically destroyed the business portion of Santa Rosa. (Plates 74, 75, 76, 77, 78, 79.) The equivalent of some 7 to 8 blocks was destroyed by the earthquake, and from 4 to 5 blocks by the fire. Conflicting reports are of course given as to the extent of earthquake damage in the burned district. The insurance companies have worked without any joint commission and no data were obtained from their agents. Judging from the unburned blocks adjacent, the buildings in the burned area were badly wrecked. One man told me that a book-store — Fourth Street, between Mendocino and B Streets — was not badly hurt by the quake and that he was in the lower floor and there was not much damage. In continuing his story, he stated that people were burned to death in the upper story of the same building because they were so caught in the débris that they could not be extricated.

The accompanying map (No. 16) shows the areas destroyed by the earthquake, and by the fire, as plotted in the office of the county surveyor, Mr. Newton Smyth. Other business men have since examined the map and agree to its substantial accuracy.

The residence portion of the town suffered to quite an extent. Chimneys were generally thrown down or so badly cracked as to necessitate their rebuilding. From twenty to twenty-five residences were thrown to the ground by the collapse of their underpinning, and badly wrecked. In cases which I personally inspected, houses close by, on ground apparently just the same, were but slightly damaged. The difference seemed to be in the character of the structural work. No uniform direction of fall was found in the wrecked residences. The reports of residences thrown "so many feet" were accounted for on investigation by the height of the underpinning which evidently determined the amount of motion. The accompanying photographs are illustrations. Thruout the town there were numberless minor injuries to plaster and fragile articles.

The physiographic results of the shock seem to be confined to some minor cracks in the vicinity of the cemetery with the possible addition of some small cracks near the creek bed adjacent to the tannery, as given in the detailed report below:

Mr. J. C. Parsons, city engineer, reports that he has found no changes in alinement since the shock. He thinks there are no changes in level, but has not yet made any accurate measurements of level. No disturbances of streets or sidewalks were found, such as are common in San Francisco.

Below are some detailed reports obtained from residents of Santa Rosa and vicinity. Few people on the street at the time of the shock were so situated as to make any valuable observations of the immediate and direct results of the earthquake.

Mr. J. W. Brown was living on Tupper Street, between Main and Brown Streets, about 5 blocks southeasterly from the court-house. His testimony is of value, as he was not distracted by any destruction of buildings in his immediate neighborhood. He was up at the time of the first shock and went outdoors to see if he could notice any waves in the ground, earthquake waves having been a subject of discussion with him in recent conversation. On going outside he heard a great noise from the west and saw the treetops waving. The noise and motion of trees approached him, and he took hold of a small tree near by for support. This tree was torn from his grasp. The ground seemed to be in waves "about 2 feet high and 15 feet long." Looking toward the court-house, he saw the dome swaying west and east, "maybe north of west," more or less in line with him, he added. The dome fell with about the third swing which he noticed.

Mr. Green Thompson was engaged in street sweeping at the time of the shock, and first heard a rumble like a wagon going over cobble-stones. He ran around the corner (Third

Santa Rosa.

Santa Rosa.

Santa Rosa.

Santa Rosa.

and Main Streets) and stood in the street between the Grand Hotel and the court-house. He states that he saw the dome swinging southeast and northwest, tho later in describing the motion he added that it was swinging up and down Third Street, which runs south of west and north of east. "With the last swing the ground came up short and stopt," and then the building fell. "All the buildings fell at once; no one first." The dome of the court-house fell east. Down Fourth Street the dust was so great that he could see nothing. He is sure that he heard but one crash.

In general, inquiries as to direction of fall of buildings met no definite answer, or else the answer was very definite with no indication of good observational basis. Many told me that there was no direction of fall; that the buildings simply crumbled to the ground.

The Masonic Temple and the Theater, I was told, fell so directly downward "that the débris did not extend beyond the walls 10 feet in any direction." This was substantially my observation on passing thru the ruined district on May 1.

Mr. M. W. Keithby, the watchman at the tannery, F and Second Streets, says that the liquor in the vats was thrown straight up and then splashed out on all sides. The tanks tipt to the west. A 3-story frame shoe factory on the north side of the tannery grounds went completely down — being flattened with but little direction of fall. One of the foremen said that the fall was slightly to the north and that heavy machinery was found close to the north wall on the third floor.

A teamster working in the creek just south of the tannery says that he noticed cracks an inch wide and several rods long a few days after the shock. He "thinks the cracks were not there before."

Mr. Searey, a teacher in the High School, stated that the vibration was east and west. In describing the shock, he stated that in coming thru a doorway facing west, he was thrown against the north casing.

A rather large 1-story frame building on Eighth Street with a brick and stone foundation was shifted N. 3° W. On A Street, near Fifth, a cottage fell to the south. The house at Johnson and Mendocino Streets fell to the north, while of the two houses at Mendocino and College Streets, one fell southeast and the other north. On Fourth Street, near E, a residence fell to the east. On MacDonald Avenue, Mr. Weaver found two houses that fell to the north. The lack of harmony in the direction of fall, and the short time, prevented an investigation of the direction of fall of all the residences wrecked.

The main Santa Rosa Cemetery, just beyond the city limits on the northeast, was badly wrecked, but not to such a degree as the cemetery at Sebastopol. The direction of fall of monuments was carefully noted, but no indication of regularity resulted. Of square monuments of approximately equal size and conditions, 12 fell north, 10 south, 7 east, and 13 west. (See plate 80A, B.)

The most marked physiographic effects in the vicinity of Santa Rosa were found near this cemetery. Just north of the cemetery hill is a swampy depression. Part of this settled 2 or 3 feet with the formation of a crack along the side, extending for some 200 feet. The cemetery is on a low hill which the sexton reports as being sand, gravel, and clay, but which shows a rocky outcrop, on the eastern side, near the base. A crack an inch or more wide was found on the northern end of the hill near the swamp mentioned above. This crack could not be followed for more than 100 feet, altho the sexton reports that at first it extended 2 or 3 times that distance. A small water-pipe on the southern part of the hill, running north and south, was pulled apart. A pipe on the northern part of the hill, running east and west, is reported by Mr. Weaver as pulled apart about 4 inches. On the southwest of the cemetery hill, Mr. John Livsey reports that several fine cracks formed across the road running north and south, and that the dust was blown away near the edges of the tracks. He also reports that the trees along the road were swinging very definitely in line with the road, which here runs northwest. The only other physiographic effects found were at the County Hospital, a little more than a mile north of the cemetery. Here low ground at the foot of a small hill sank for some 2 feet and springs were formed. These springs were reported as still running the last of July. No connection could be found between the disturbances at the cemetery and the hospital. In the cemetery a large tank fell to the north. The tank was close to the water-pipe that was pulled apart on the north and south line.

At the Catholic Cemetery, some 2 miles southeast of Santa Rosa, only one monument fell out of some 20 of the class that were commonly overthrown at the main cemetery. Going farther southeast thru Bennett Valley, no physiographic effects were discovered and few chimneys were thrown down.

Not knowing of Mr. Butler's trip to the southward, I duplicated part of his work to the south of Santa Rosa, on the Petaluma road, with the same results as stated in his report.

Up the alluvial slope of Copeland Creek about 7 miles south of Santa Rosa, I found that chimneys were much more damaged than on the road northward from the creek to Santa Rosa, which usually follows the edge of the foot-hills.

Northeast of Santa Rosa, Mr. Butler reports that along the road to the Rincon District the damage was very slight, as it was also on the road running northwest from Santa Rosa toward Fulton. This road, it should be noted, keeps close to the foot-hills.

The most severe damage in the country around Santa Rosa was found to the westward in the vicinity of Sebastopol.

The great damage in Santa Rosa may be accounted for by the physiographic conditions and by the weakness of the buildings in many cases. The sand for mortar has usually been obtained from the creek and contains considerable loam. Some of the mortar seems to have been made with good sand and with cement. The old bank building, just west of the court-house, stands alone in that part of the wrecked area, a monument to good work. Usually thruout the wrecked area the mortar taken from the walls is easily crumbled to incoherent sand by pressure of the fingers.

(E. C. Jones.)—Very little damage was done to the gas mains in Santa Rosa as a result of the earthquake, but there were several explosions in the mains during the fire which followed. In several cases the cast-iron mains were blown apart; and when uncovered, the ends were found to be separated from 1 to 3 inches, according to character of ground.

At the generating plant the damage was principally to the brick building. The entire east wall fell outward, and the remaining walls were badly cracked. The columns of the gas-holder frames were thrown down, and the water-level in the tank was lowered about 6 feet. The holders were twisted out of position about 20°.

(C. T. Wright.)—There seem to have been two distinct motions in Santa Rosa, one from north to south, or more properly from north 30° west to south 30° east, the other roughly from west to east. The former motion seems to have been noticeable over a larger area and probably was the more violent. There is a belt along the Northwestern railroad tracks in which the west-east motion was specially noticeable, as shown by observations at the flour mill, the woolen mills, and the cannery. West of this belt, at the tannery on West Sixth Street, a distinct north-south, or northwest-southeast, motion was indicated, while east of this belt, in the region from Washington Street to A and B Streets, the northwest-southeast motion was specially evident and is the predominant motion. At Humboldt Street it becomes somewhat confused.

Most reports agree as to "choppy," rotary, or up-and-down movements following the pronounced horizontal movement, or between successive horizontal movements. This suggests interference of waves. The observed phenomena might be explained by the passage of a series of long, very rapid northwest-southeast waves of great intensity; and simultaneously or immediately following the beginning of this series, a second series of comparatively short west-east waves. Supposing the crest of the latter to have reached a line in the neighborhood of Washington, A, and B Streets, and the trough of this series to be near the Northwestern railroad tracks when a crest of the northwest-southeast series swept down, the two motions would tend to neutralize each other in the neighborhood of the railroad tracks and augment each other in the other district. It may be supposed that after the passing of this northwest-southeast crest and before the passage of another, the west-east waves were specially noticeable near the railroad tracks and did their destructive work there. If this theory be correct, another "trough" should be found between Mendocino Street and the Southern Pacific railroad station. The somewhat promiscuous directions of falling objects on Humboldt Street might indicate the approach to this region. To test the theory would require further observation.

(Marvin Robinson.)—Mr. Robinson of Santa Rosa states that he was just across Fourth Street and north of the court-house, and that at first the dome of the court-house seemed to be almost over him, and a few seconds later fell directly east. The brick buildings near him all fell east. He believes the street to have been vibrating in a vertical direction at the close.

City Hall, Santa Rosa.

A. House moved 7 feet by collapse of underpinning, Santa Rosa. R. S. H.

B. House lurched to north, Santa Rosa. R. S. H.

C. Wrecked dwelling, Santa Rosa. R. S. H.

D. Wreck of brick structure, Santa Rosa. R. S. H.

A. Cemetery, Santa Rosa. R. S. H.

B. Cemetery, Santa Rosa. R. S. H.

C. Cemetery, Sebastopol. R. S. H.

D. Cemetery, Sebastopol. R. S. H.

A. East side of main street, Sebastopol. R. S. H.

B. Wrecked buildings, Sebastopol. R. S. H.

C. Stone house 1.5 miles southeast of Tomales, where two people were killed at time of earthquake. R. S. H.

D. Wrecked church, Tomales. R. S. H.

(Charles Kobes.) — The vibrations in Santa Rosa were at first north and south, then east and west, and finally vertical. Mr. Kobes relates an instance in regard to the earthquake which occurred about 8 years ago. At that time sulfur fumes came up from under his house which almost drove his family from home. On April 16, two days before the shock, sulfur fumes came up equally as strong, and he told his family that he believed it meant another earthquake.

(Mr. Miller.) — The vibrations in Santa Rosa were at first north and south, then east and west, and finally vertical.

VICINITY OF SANTA ROSA.

(Drury Butler.)—Near the top of Taylor Hill, in a marshy place, there was a landslide, the earth having slid on a clayey bottom. In Bennett Valley the country is hilly, with some underlying basaltic formation, and very little damage was done. Beyond a distance of about 3 miles from Santa Rosa, only an occasional chimney was found that had been injured, and the effect was much less as higher ground was reached. Along the Sonoma road to the Rincon district school, beyond 2 miles from Santa Rosa, the damage was very slight. The road follows the creek, but here the hills come down to the creek. Over half the chimneys were uninjured, and none were completely thrown down except right along the creek. No bottles nor glasses were thrown from the bar-room shelves. Along the creek the shock was more severe than back from it. In the vicinity of the Sonoma County Hospital, the soil is very like the Santa Rosa soil and the shock was felt more. Glasses and bottles were thrown from the shelves in the bar-rooms, and at the hospital a marshy place along the creek slipt toward the creek and the flow of springs was greatly increased. The hospital also was pretty badly damaged. A trip was made out on the Petaluma road to the Copeland district school, then to Cotate, to the Durham district school, and back to Santa Rosa. The road followed the base of the hills for about 7 miles, then turned into the valley and was on the valley floor the remainder of the way. On the hillside very little damage was done, even to chimneys, while in the valley the chimneys were as a rule thrown down. I could hear of no cracks in the ground in the valley; and in only one place, about 2 miles from Santa Rosa, on the Petaluma road, could I hear of any increase or change in the flow of springs.

From these observations it was apparent that lines of equal intensity would follow the contour and geological lines of the country, and that the character of the soil on which a building stood determined the effect upon it, or the apparent intensity of the shock.

The general motion of the waves of the earthquake, as reported to me, was from north to south.

Cotate (C. L. Jeffrey). — At Cotate, 9 or 10 miles south of Santa Rosa, on the open level floor of the valley, the surface of the earth waved like water; objects were thrown southeast; hanging objects swung northeast and southwest. Only one maximum was observed. Trees swayed heavily, and there was a sound as if a strong wind were coming before the earthquake began.

Wells East of Santa Rosa (E. S. Larsen). — At the city pumping station, 1.5 miles east of Santa Rosa, there are 4 wells dug 50 feet and connected with a tunnel 450 feet long. Within each well there is a bored well 8 inches in diameter and 108 feet deeper than the dug well. The water began to rise immediately after the shock, and has risen, May 8, 1906, 15 feet higher than it was before, altho the pumps have been run to their full capacity. The water tastes more of sulfur since the shock. The shock caused the pipes and boiler to leak.

At Peters' ranch the warm spring was little affected. Mr. Peters, the younger, says that for a day or so after the shock the water in the spring was lower, but that it is now normal.

Sebastopol, Sonoma County. Population 1,300. (R. S. Holway.) — Several buildings were completely wrecked. (Plate 81A, B.) The 2-story Knowles Hotel, a frame building, veneered with brick, went completely down, flattening the first story. The walls of the hotel fell out, so that the occupants of the rooms in the second story walked out on the ground level. The upper part of a brick stable was wrecked; also the upper part of the Walker Building, which is to the north in the same block. Three stores just south of the post-office were completely wrecked. North and south side walls both fell south, one falling out, the other into the building. The contents were badly scattered. A new frame house, a 2-story structure, was moved from 3 to 8 inches on the concrete foundation and the walls were cracked and wrenched.

The cemetery, about 0.7 mile west, is more severely wrecked than the Santa Rosa Cemetery. Nearly 90 per cent of the monuments of any size were thrown down. (See plate 80C, D.) The great majority of square monuments fell south. The heavy Talmage monument was moved southeast on its base. The sheet lead under the southeast corner shows one set of regular striæ; the lead under the north corners is untouched. Cracks occur in the ground near the cemetery and near the Burbank ranch.

Mr. R. M. Hathaway, writing from a place 3 miles northwest of Sebastopol, sends the following information:

Many frame buildings in the vicinity were thrown from their foundations and some of them so damaged as to be uninhabitable. Chimneys were all shaken down, also brick furnaces. There are no brick buildings around here. The earthquake at my point of observation seemed to have an oscillatory motion, the vibrations traveling north and south. My house is a two and one-half story frame building on a low ridge of sandy hills running north and south, west of and parallel to the Santa Rosa Valley. All objects seemed to have a tendency to move toward the south. All furniture against the north walls was thrown down violently, some on the south wall going down also; while some remained upright as tho supported by the wall. Furniture against the east and west walls was moved toward the south.

The chimneys all fell to the south. Window casings on east and west walls were wrenched so as to break some glass. Injury to the frame houses in the vicinity, apart from damage due to falling chimneys, seemed to consist in throwing them from their foundations, and where a house consisted of several portions in the form of wings, these were separated. The foundations in some instances crusht, letting the buildings down to the ground. Well-constructed frame buildings, where the foundations were low, did not collapse. At the Sebastopol Cemetery, about a mile west of Sebastopol, the monuments were nearly all overthrown, falling in all directions, altho I estimate that fully half of them, if not more, fell to the south. I did not notice any change in water level, the change if any being small. There were some fissures made in the ground near here.

President David Starr Jordan contributes the following note relative to the effects of the earthquake at Sebastopol:

The violence of the recent earthquake was very great at Santa Rosa; much less at Petaluma, which is equally near the crack and on still flatter ground; and still less at San Rafael farther south but the same distance from the earthquake Rift. At Sebastopol, 6 miles west of Santa Rosa, the violence was relatively still greater, the village being tremendously shaken up. At Burbank's farm, 0.5 mile west of Sebastopol, I noted these things: In the lot adjoining, to the south, the soil being clayey, there is a large crack running northwest and southeast, or nearly so, and, according to Burbank, 0.25 mile long. It runs thru the fields and weeds, and was very distinct on August 6. The end of this crack comes up against the sandy hill occupied by Mr. Burbank's orchard. The crack does not show itself in the hill, but on the east side of the line of the crack the rows of trees and plants were shifted toward the south — or, if you prefer it, those on the west side toward the north — 2 or 3 feet. A well of Mr. Burbank's, sunk in the sandy ground, is bodily shifted, without being injured, along with the rows of plants between which it is placed. No crack appears at the surface in Burbank's ground, but on the other side of the hills, to the north of it, I was told the crack reappears.

According to the record of Matthes and Holway, similar cracks appear in the same line 4 miles and 9 miles north of Petaluma, and there seem to be other breaks on the way toward Point Delgada. It seems certain that this first crack is an earthquake rift, and that the disturbances at Santa Rosa and Sebastopol are due to this and not to the main Rift which lies parallel to it to the west.

Mr. G. K. Gilbert also visited the Burbank farm at Sebastopol, and contributes the following note referring in part to the cracks discust by President Jordan:

Mr. Luther Burbank gave me an account of personal experiences and of various phenomena at Santa Rosa, and I record such items as are supplementary to Professor Holway's report. Mr. Burbank was awake at the time. He immediately got out of bed, but found he could not stand, and settled back against the bed, holding on to the window casing and bedpost. The initial impulse was from the west, and during the first portion of the earthquake the motion was oscillatory, east and west. Then it became oscillatory north and south, and at the close there was a complex motion which he compared with that of a vessel in a choppy sea. From the window he saw trees waving, and after the tremor had ceased he seemed to see a continued disturbance in the foot-hills at the east, as tho the tremor was retreating in that direction. He said that practically every one in Santa Rosa who was on foot at the time was thrown to the ground, but that men on bicycles were not upset. During more than 30 years' residence in Santa Rosa he had felt about 130 earthquakes. None were comparable in violence with the recent one, tho several had broken chimneys. A number of earthquakes which were felt generally in Santa Rosa had not been felt at all in Sebastopol, and he thought that Santa Rosa was peculiarly subject to shocks.

A shock was felt in Santa Rosa on April 17, 1906.

Mr. Lawrence, foreman on Mr. Burbank's farm at Sebastopol, stated that men standing or walking at the time of the shock were thrown from their feet, as were cows and horses. The small house on the Burbank place was moved from its foundations a few inches downhill, and Mr. Lawrence mentioned a number of houses which had moved various distances, the direction in every case being downhill. On the Burbank farm a small landslide occurred, a layer of moist soil only a few feet in thickness moving down the slope, introducing bends in various lines of cultivated plants. I saw another feature of this sort on an adjacent farm, and was told of others which I did not visit.

In a general note on the intensity of the earthquake, appended to detailed observations which have been incorporated in the foregoing account of the distribution of intensity, Mr. G. K. Gilbert says:

In general the violence seems to have been less in Petaluma than in Sebastopol, Santa Rosa, or Maacama, notwithstanding the fact that it is nearer the main fault. As compared with Sebastopol and Santa Rosa, however, Petaluma seems to be on relatively firm ground, excepting a small district bordering the marshes. In a general way, I think the relative violence in the three towns corresponds to the character of their foundations, but considering the district as a whole, in relation to districts nearer the main fault, it is clear that the intensity was exceptionally high.

Altruria, Sonoma County (R. S. Holway). — About 5 miles north of Santa Rosa, at Altruria, cracks are said to have opened in the road, and springs to have flowed for a short time. There was no indication of either last May.

Mark West Springs (R. S. Holway). — The concrete walls of several springs were cracked and damaged. Chimneys fell on the house. The springs are reported as flowing much more freely, and the temperature of two of them is said to be very much higher than before the earthquake. They are now quite warm to the hand, and it is said that they were formerly cold. I could get no reliable information as to temperatures, as no records were kept. The increased flow is independently indicated by circumstantial evidence.

Windsor. Population 130. (R. S. Holway.) — Here 2 or 3 brick buildings were badly wrecked, and the water-tank at the railway station was overthrown. The cemetery

about 1.5 miles south of Windsor is on low, rolling hills. Only 4 monuments out of 35 to 40 of the class wrecked at Sebastopol and Santa Rosa were thrown down.

Guerneville. Population 500. (R. S. Holway.) — In this town all brick buildings were badly wrecked. Chimneys generally fell. The Commercial Hotel, a frame building, was twisted slightly, contraclockwise. Under the house of Mr. Turner, which is built on piles, the piles on the east side were thrown 8 inches east and those on the west side 4 inches north. Mr. Turner reports the shock as clearly from north to south. His workcases were thrown from north to south. The cemetery, which is on a terrace 190 feet by aneroid above the flood plain on which the town stands, was very slightly affected. One monument is reported to have fallen. Three or four show slight shifting.

SANTA ROSA VALLEY TO SAN FRANCISCO BAY.

Petaluma. Population 3,900. (R. S. Holway.) — The inspector of chimneys reported that the great majority of chimneys fell. (See fig. 64, page 341.) In east Petaluma, on the lowland, all but 4 fell. Three brick stores had the entire front thrown out, and 10 or more had tops of fire-walls thrown down. The stone hay-barn of McNear was wrecked; also a corner of the stone warehouse. The 2-story brick silk factory had every corner wrecked. The central tower and the large brick chimney were thrown down. The ice plant near the station had the high brick stack thrown, wrecking part of the building. The Golden Eagle, a 4-story brick flour mill, was not damaged; but the 1-story addition and a 1-story stone warehouse had portions of their walls fall. There are no authenticated reports of cracks in Petaluma nor in the low tidal lands immediately adjoining. Vague reports to this effect were not verified. (See plate 73A, C.)

Lakeville, Sonoma County (C. A. Bodwell). — This place is about 6 miles southeast of Petaluma, on a hill slope near the tidal marsh of Petaluma Creek. Chimneys were overthrown, plastering badly cracked, and dishes broken. Chimneys and objects were thrown to the southeast. There were 2 maxima in the shock, of which the second was the stronger. The movement was from southeast to northwest.

Petaluma northward up Sonoma Mountain (R. S. Holway). — Northeast about 2 miles across the low land, chimneys were thrown down and furniture was moved. No cracks were reported in the ground. Thence northward to an elevation of over 1,800 feet, nearly all the brick chimneys were down. Houses are usually small 1-story frame buildings. Articles were reported thrown from the shelves and furniture moved. "House shaken so severely I could not walk across the floor," was a common statement. No landslides were reported, altho quite a number occurred in this region during the winter.

Petaluma to Sebastopol (R. S. Holway). — A drive along this road, which keeps near to the western line of Santa Rosa Valley, showed an increasing intensity of shock from Petaluma toward the northwest. Chimneys were quite generally down along the entire line. At Jur's ranch, about 2.5 miles northwest, 3 cracks with a very slight dropping of small blocks between them, are reported. A temporary flow of water was reported from a crack by the road. Small cracks were reported on the road about 4 miles from Petaluma. Near Stony Point school-house, about 9 miles out, 19 cracks across the road were reported by the teacher. At Nason's ranch there is a landslide of the bank of the lagoon 100 yards or more in length. Four miles from Sebastopol is another landslide at Davis' ranch, where a house was thrown from its underpinning. Cracks were reported at Hansen's and several places. There is a distinct increase in cracks and landslides in the approach to Sebastopol.

San Rafael, Marin County. Population 3,900. (R. S. Holway.) — "Half the chimneys down" was a frequent report. Most of them were rebuilt at the time of my visit. "A. W. Foster's place, on the hills to the north, had 100 chimneys and only one fell." A brick

building one block north of the station had the top of the end wall thrown down. A 3-story brick hotel was very slightly cracked. On May 1 the town showed no sign of earthquake to the casual observer. A crack one block long, north and south, in low land near the station is reported. At the Hotel San Rafael 2 chimneys fell on the roof and porch. At the cemetery, 2 miles north of San Rafael, only 3 monuments and some 8 crosses fell. Mr. Weaver reports that on 12 houses near the station and the Hotel San Rafael chimneys fell east. My own inquiries up town were generally answered by "all directions," so far as chimneys were concerned.

San Anselmo Theological Seminary is a stone building on a rocky knoll, not tied by rods. The tower of the library fell, part of it crashing thru the roof to the first floor. At the dormitory the coping on top of the walls and the chimneys have fallen on all sides of the building.

Mr. Frank M. Watson reports the following effects of the earthquake in San Rafael:

In the drug store of Mr. Inman, Fourth and C Streets, hundreds of bottles were thrown from shelves running east and west, and bottles on shelves running north and south were thrown parallel with the shelving.

At St. Paul's Church, Fourth and E Streets, the chimney moved 0.375 inch bodily to the south, and bricks were crusht out on the north side. A chimney to the west of this was overthrown. The Grammar School, west of this church, had 2 chimneys down. The High School to the south suffered no damage, but bottles moved on a shelf mostly to the west.

At the house, 17 Fourth Street, on level land, the occupants felt 2 shocks with a very short interval between, the first being longer and lighter than the second. The general direction of movement was thought to be east and west. The chimney fell east. The clock stopt. The shock was lighter on the rising ground to the south, as inferred from less damage to chimneys in that direction.

At the house of Mr. W. Robertson, 20 Fourth Street, on level land, an up-and-down motion was experienced. The middle portion of the shock was the heaviest, and it was then that a marble mantel fell east.

At the building occupied by Mr. George D. Shearer, 306–310 Fourth Street, on level land near the depot, there is a crack running north and south; 4 chimneys fell west and 2 east on a flat roof. The north end of a wall of the building fell out down to the level of the second-story floor. The coping on north and south walls fell off, and plaster was badly cracked on inside partitions. In the adjoining house, Mr. Joseph La Franchi was awake, his bed lying east and west. The shock was north and south. The chimney from the next building crashed down thru his house.

At the office of the Western Union Telegraph Co., 608 Fourth Street, a clock facing the east stopt at 5^h 13^m A. M.

At the jewelry store of Mr. J. D. Bennett, 709 Fourth Street, on level ground, 2 large accurate pendulum clocks hung 10 feet apart, one on an east wall and the other on a west wall. One stopt at 5^h 12^m 35^s, the other at 5^h 13^m. These clocks do not vary 3 seconds in 24 hours, and were right at noon of the previous day.

At the Grand Central Hotel, 720 Fourth Street, on level land, an up-and-down motion was felt, then an oscillation from east to west. The building, built of brick in 1860, is 3 stories high. It shows a crack 0.5 inch wide in the east wall, extending from the roof to the second floor, and there were also cracks in the south wall over the windows. Some plaster fell and one chimney was broken.

At the house of Mr. George L. Richardson, county surveyor, on Harcourt Street, on level land, 2 shocks were experienced; the first apparently heavier than the second, both being of about the same duration. The oscillation was from east to west. No damage to residence. At his office in the court-house, the marble back of a washstand was thrown west, and plaster was cracked on east wall.

At the house of Mr. L. Armstrong, 206 Ross Street, on a hillside 50 feet above sea-level, milk and cream slopt from pans a little north of northwest. There was no damage to buildings or chimneys in the neighborhood. A slackening in violence was noticed about the middle of the shock.

At the San Francisco and North Pacific railroad depot, on level land 7 feet above sea-level, the night operator, Mr. Vernon Grisham, reports first an oscillation, then an up-and-down movement. Buildings shook for 2 minutes by the watch in an east and west direction.

The clock stopt at $5^h\ 12^m\ 30^s$. It does not vary 2 seconds in 24 hours, and is set daily by telegraph. A crack was formed in the ground 100 feet long, running north and south. The greatest damage was half a block north of the depot. The depot itself suffered no injury.

At an unoccupied house on D Street, opposite Ross Street, a chimney moved 1 inch west and twisted clockwise about 5°. A second chimney moved bodily westward 0.75 inch, and was similarly rotated. All the chimneys in this vicinity were down.

At the grocery store of E. Kolepka, First and E Streets, a 2-story brick building, all 4 chimneys were cracked but left standing. Goods in the store were thrown from shelves running north and south, and to a less degree from shelves running east and west. Some plaster fell from the ceiling, and all chimneys in the neighborhood were damaged or thrown.

Mr. W. Robertson, city inspector of chimneys, reports that there are 1,200 chimneys down and many more damaged. Probably 100 were twisted, the amount and direction of the twist being quite variable. Most of the chimneys, however, fell northeasterly. On the hills the shock was lighter.

At Scheutzen Park, 1.5 miles east-southeast of San Rafael, on land 7 feet above sea-level, 2 shocks were felt: the first light and long, the second hard and short, the direction of movement being east of north. There was no serious damage to buildings or chimneys, but water-pipes were broken, and there were many small fissures in the neighboring ground, running north and south.

At the Catholic Cemetery, 2 miles north of San Rafael, on rising ground, an up-and-down movement was experienced. A clock in the house of the guardian tipt over, but no damage was occasioned to buildings. There were 3 monuments and a few light crosses overthrown in the cemetery. The chimney of the brick yard, a mile to the east, remained intact.

At the residence of Mr. C. Day, near the San Anselmo Seminary, the east chimney was twisted clockwise 10°; and the chimney on the church next door was affected in the same way. Things on the walls fell east. One chimney fell west.

Novato (F. M. Watson). — Town is situated on sloping ground. Mr. A. Scott states that 2 shocks were felt, the first east and west and light, the second north and south and heavier. In the grocery store canned goods were tipt south on shelves running north and south. Chimneys as a rule were not damaged, but the top of Mr. Scott's chimney moved 1 inch to the southwest. Two clocks were stopt.

Sausalito (F. M. Watson). — Nearly all chimneys were thrown, most of them falling about northwest. Mr. Landon's 1-story house, on a hill about 125 feet above sea-level on hard rock, was moved slightly to the west on its foundations. On this house 2 chimneys fell to the west. The earth was cracked on the low ground near the station, the fissures running north and south. The railroad clock stopt at $5^h\ 13^m$.

Mt. Tamalpais (W. W. Thomas, of the Weather Bureau Observatory). — The observatory is in a slight depression between the east and middle peaks of the mountain. A number of rounded peaks form a prominent ridge about 3 miles in length, extending nearly east and west, and having an average elevation of about 2,500 feet. Rocks are exposed everywhere at the surface. No chimneys nor other tall structures were overthrown, but ornaments and small objects were thrown from shelves that ran north and south, or were more or less displaced in a direction somewhat south of west or north of east from their original positions. No objects fell from shelves that ran east and west, and no object moved north or south of its usual place was observed. An anemometer fell from the instrument stand to the floor, where it lay in a direction about west-southwest of its place on the stand. The instrument is so balanced that it takes no greater force to overturn it in one direction than in another. There were 2 maxima in the shock, and the first was the stronger. The direction of movement was about west-southwest and east-northeast. A vertical movement is inferred from the fact that all four of the direction arms on the triple register recorded at one time. This would indicate that the instrument received a sudden jar or series of jars in a vertical direction, for no electrical contact nor any amount of lateral shaking can cause all four of these arms to record at the same time. Some plaster fell, and a part of a loosely constructed stone wall was thrown down.

Angel Island Light Station (Mrs. J. E. Nichols). — The shock resembled the jolting of a railway train which, running at full speed, had left the tracks and was bumping over the ties. It was accompanied from the beginning by a loud noise which gradually decreased as the jolting motion ceased. Water standing in a pail was thrown out 6 feet from northeast to southwest. The clock was stopt. The bay was calm. A cement pavement was cracked to pieces. The station is on solid rock.

Yerba Buena Island Naval Training Station (Capt. A. T. Marix). — A heavy vibratory shock was felt.

Alcatraz Island. — A heavy shock was felt in which there were 3 maxima, the middle being the strongest. Objects were overturned in every direction.

Southeast Farallon Island (James A. Boyle, assistant observer of the U. S. Weather Bureau). — The ground is composed almost entirely of solid rock. The Weather Bureau building is on a narrow neck, 15 feet above sea-level, between 2 peaks about 300 feet high. Objects in this building were thrown east. A stone weighing about 100 pounds slid 6 inches west by south, and was turned slightly counterclockwise. There was no rotary nor vertical motion felt. There were 2 maxima, of which the first was the stronger, and the motion was east and west in both cases. The only damage done was the opening of a crack across the entire front of the fireplace. Two rock slides, of about 100 tons each, occurred on the west end of the island. At $10^h\ 06^m$ A. M., April 18, two distinct vibrations were felt. They were also felt by Mr. Legler, of the Weather Bureau Station at Point Reyes Light-house, with whom Mr. Boyle was talking over the telephone at the time, 3 seconds before they were felt on the island.

SONOMA VALLEY.

In the Sonoma Valley Mr. E. S. Larsen made the following observations:

Melita. — Chimneys are all down and plaster somewhat broken. Shock somewhat less than at Santa Rosa.

Between Melita and Kenwood conditions were about the same. Nearly all chimneys were thrown down or twisted.

Kenwood. — Most of the chimneys were down. The brick hotel was not much injured, but a few poorly constructed 1-story stone buildings were somewhat damaged.

Glen Ellen. — Chimneys were nearly all down. Popp's poorly constructed 2-story stone building was damaged so that the upper story had to be torn down. One wall of a brick building whose braces had been removed to make room for a stairway was much cracked. The other walls were little damaged. A clock with a half-second pendulum, facing south, stopt at $5^h\ 13^m$. A fireman and an engineer on the San Francisco and Northwestern Railroad say that the shock started at exactly $5^h\ 13^m$.

Eldridge, State Home. — All chimneys were thrown down and the upper story of each of the 3-story brick buildings was so damaged that it had to be removed. In a few cases there were cracks in the lower stories. One large electric clock with a second pendulum, facing northeast, stopt. Another clock with a half-second pendulum, facing southwest, did not stop, but its pendulum was turned about 20° clockwise.

Aqua Caliente. — Most of the chimneys were thrown down and the plaster was cracked. There was little damage to the brick and adobe houses.

Boyes Hot Springs. — An artesian well 97 feet deep now yields a larger stream.

El Verano. — Nearly all chimneys were down. A clock with a half-second pendulum and facing east stopt at $5^h\ 15^m$.

Sonoma. Population 650. — Chimneys were nearly all down. Some of the brick and adobe buildings were damaged, but the shock was much less severe than at Santa Rosa. At the Hillside Cemetery, 0.125 mile east of the railroad depot, out of about 18 tombstones over 4 feet high and having the usual square or round section, 13 were

turned on their bases from a few degrees to 20° counterclockwise; 2 were down and 2 had the top ornaments thrown off. At the Catholic Cemetery, out of 6 tombstones of the above type 1 stone was turned clockwise and 1 counterclockwise. This cemetery is in the valley. The Valley Cemetery has 2 tombstones out of 6, of the above type, turned counterclockwise. The Sonoma Valley High School had 3 chimneys out of 6 turned counterclockwise; the other 3 fell. I found chimneys on 3 other houses turned counterclockwise, and 1 chimney turned clockwise. Two miles south of Sonoma, at Mrs. William Clemens', all 3 chimneys were turned counterclockwise. Mr. T. A. Lewis, physics teacher at the High School, described the shock as being at first a temblor, vibrating northeast and southwest, then a short calm, and finally a longer and harder twisting shake. Dr. Grey, of the State Home at Eldridge, and several others, gave a similar description.

Shellville. — About three-fourths of the chimneys were thrown or twisted.

NAPA VALLEY TO THE SACRAMENTO VALLEY.

Napa Valley (C. E. Weaver). — At Calistoga, population 700, a large number of chimneys fell and 2 brick buildings were thrown down. Clock stopt. A few local slides on the south side of Mount St. Helena were confined to the alluvium. At the town of St. Helena, population 1,600, a stone building of the California Winery Association was slightly damaged, and 8 brick chimneys in the town were overthrown. At the Veterans' Home, at Yountville, the buildings constructed of brick and stone had two corners thrown down and the walls cracked. At Napa many brick buildings were cracked, and walls thrown down. Chimneys were generally overthrown. No damage was sustained by the concrete buildings, nor by the machinery contained in them, at the cement works at Napa Junction.

Calistoga, Napa County (Dan Patten). — Nothing was thrown down in the house. In the milk-house cream was thrown from full pans on the northeast side. A large water trough near the house had the water thrown out on the northeast side. Some large rock was thrown down from cliffs up on the mountain (Mount St. Helena) at an elevation of 4,000 feet on the northeast side. Mr. Patten was in front of the house, the east side, and heard a rushing noise. He had time to look up the road to the south, and then turn and look north, expecting to see some fast driving team, before the shock came. He felt first a tremor, and then 2 heavy thumps a few seconds apart; then tremors gradually decreasing until probably 0.75 minute had elapsed.

St. Helena, Napa County (F. Blachowski). — At the Sanitarium near St. Helena, which is on a hillside with rock near the surface, objects were thrown mostly toward the east. Some chimneys were turned counterclockwise, and a twisting motion was felt. There were 2 maxima in the shock, the second being the stronger.

Rutherford, Napa County. — Mr. Joseph Mora was starting out on his bicycle when he heard a loud noise like that of a country wagon; he stopt and was then shaken by the earth moving violently; the trees swayed wildly. The sound and the shock came from the southwest. All the wine-cellars and structures that were not well built were partially thrown down. Chimneys came down from all buildings. Niebaum's wine building showed no cracks.

The Veterans' Home (A. Brown). — The Home is on sloping bench land in the foothills on the west side of Napa Valley. The chimneys on some of the buildings were twisted around, and some tumbled over. Mr. Brown felt his bed rocking north and south for about 15 seconds. A clock stopt. Some plaster fell at the new hospital. Only one maximum was observed in the shock.

Mr. J. M. Clark, of the Veterans' Home, who maintains a seismograph of his own construction at that institution, reports that the hardest portion of the shock came, as near as he could judge, about 20 seconds after the beginning. There was a rapid increase in intensity up to that time; then came the gyratory, upward, jerky motion, which was

very severe. This continued for about 10 seconds, and then came a swaying motion, that seemed at right angles to the first.

A chimney stack, of brick, 120 feet high, belonging to the power-house on the Home grounds, was shattered. Its rectangular faces fronted to the northeast, southeast, southwest, and northwest, respectively. In two places, one about 40 feet and the other about 60 feet from the ground, the upper portion of the stack was shifted, as if the rotation were from north to west to south to east, it being understood that the motion of the earth was in an inverse direction to that of the twisted distortion of the chimney. The westerly corner hardly moved while the easterly corner was shifted several inches. The lower fracture had a displacement of about 2 inches at the easterly corner, and the upper fracture had a similar displacement. In the dispensary of the Home, the first portion of the shock threw the bottles from the shelves upon northwest and southeast walls. The latter portion of the shock precipitated the bottles from the other walls. This was proven by finding articles from the northeast and southwest shelves lying on top of those from northwest and southeast shelves.

Napa State Hospital. — The effects of the earthquake are thus described in the Climatological Report of the U. S. Weather Bureau for April, 1906, by Mr. W. H. Martin:

At 5^h 14^m A. M. on the morning of April 18, 1906, a severe earthquake commenced, and lasted about 80 or 90 seconds. The apparent motion at the beginning was from the west by south to the east by north, a rolling motion for about 15 to 20 seconds, then a light interval for a few seconds, then a renewed force of a twisting nature, intensity IX. The ground, to the eye, seemed to be quivering; the hills seemed to have a rocking motion, the trees seemed to be shaken by the hands of a giant; everything lookt to be in motion; the air was hazy and still. Many brick and stone walls were thrown to the ground and others damaged to such an extent that they will have to be taken down. Nearly all chimneys were thrown down, and of those standing some are turned a quarter way round. Milk in pans was thrown out in an easterly and westerly direction. The estimated damage to the city of Napa is about $150,000. The damage to this institution was very light, except that the main tower will have to come down.

Napa (E. C. Jones). — The damage to street gas mains at Napa was very slight, only two leaks developing. The gas station was badly shaken up; about 10 feet of the end wall of the brick building was thrown down, falling on top of the boiler and breaking off the steam pipes. The gas-holders were badly shaken. Water was displaced from the tanks, but only one guide wheel was shaken out of place.

Wooden Valley, Napa County (H. W. Chapman). — On level alluvial ground near the base of the surrounding hills, no objects were overthrown. There were 2 maxima in the shock, of which the first was the strongest, the movement being north and south.

Pope Valley, Napa County. — The top of one very old chimney was thrown over, falling to the south. Another was cracked, and 4 or 5 bricks from the top of another fell down into the fireplace.

Mr. H. P. Gordon reports that he was in Pope Valley at the time of the earthquake, and that the shock awoke him. It seemed to be a tremor at first, then an oscillatory motion east and west. It seemed to him as if his bed were a gold pan, and he were being panned out. His house stands on rock.

Berryessa Valley, Napa County. — The shock is reported to have been quite heavy on the level land of the valley-bottom.

Vallejo, Solano County. Population 8,000. (W. D. Pennycook.) — The shock was quite as hard as that of 1898, when the brick structures at Mare Island navy-yard were very much damaged, some of them having to be taken down. The vibrations in that earthquake were lateral, nearly north and south. The vibrations of the earthquake of April 18, 1906, while equally severe, were different in character. In Mr. Pennycook's house are 2 mantels facing north and south, and a large china closet. In the earthquake of 1898 every article on both mantels was thrown to the floor, and in the china closet the crockery

was thrown from the shelves. On April 18, 1906, nothing was thrown from the mantels, but a clock, which in 1898 had been thrown to the floor, was turned around about 20°.

The postmaster of Vallejo reports that the city is on a hillside adjoining the Mare Island strait. The surface is rolling and has very little level land except such as has been cut down, which is entirely of clay and soft rock (shale). Sandstones and shales are the underlying rocks, and these come close to the surface except along parts of the edge of the strait. There was a noticeable decrease in the violence of the shock toward the middle, then an increase in severity, the latter part being the stronger. The movement was north and south. Objects hanging on gas fixtures by ribbons wound themselves up on the same. The Post-office clock stopt. The floors appeared to rise and fall. All the damage done was to chimneys; not a brick wall showed any injury. The greatest damage was done in the lower levels, the hills suffering very little.

(T. J. J. See.)—Vallejo is built on hard ground and did not suffer very severely from the earthquake. The best estimates obtainable showed that about one-tenth of the chimneys were knocked down, or so broken loose that they had to be taken down. The shock was not so severe as that of 1898, which was much more local in character. No house in Vallejo fell, and chimneys were about the only fixt objects thrown down. Various objects in the houses were overturned, such as bookcases, bric-à-brac, and dishes on shelves; and the plastering was somewhat cracked. In general, however, the injury was not great.

Mare Island (T. J. J. See). — The earthquake was much less severe than that of 1898, which wrecked many of the Government buildings in the navy-yard. None of the Government buildings was wrecked this time, nor was the damage at all serious except in the case of two or three new buildings recently erected on the "made" land near the water-front. Here the ground was thrown into violent undulations, and the buildings were so twisted that about $2,000 worth of repairs had to be made. On this soft ground the brick walls were cracked, but as the buildings have steel girders, no part of them fell except one or two top-heavy cornices. But the swaying of the brick walls tied together with steel frames caused the walls to be cracked and scaled off near the steel supports. In the case of the older buildings resting on hard ground, no cracks were formed, nor any injury reported. No chimney on Mare Island was thrown down, and only one or two were broken loose at the roof so that they had to be taken down. The amplitude of the vibrations in the soft ground at Mare Island was found by measurement to be 2 or 3 inches. This was determined from the displacement of the loose dirt around the piles supporting the steel frames of the buildings on the "made" land. On the whole, the intensity was about the same at Mare Island and Vallejo.

Prof. T. J. J. See contributes the following note on the swaying of a smoke-stack at the navy-yard on Mare Island:

> "This smoke-stack is made of steel, bolted together in sections and lined with fire-brick 150 feet high and 6 feet across at the top. Three separate witnesses, standing at nearly equal angles about the base, and something like 100 yards away, observed the tower writhing and twisting during the earthquake. The motion was described as like that of a corkscrew. All the witnesses say that the top of the stack vibrated in a circular or elliptical manner, thru a space of at least 2 diameters; that is, one diameter on either side from the mean position. The stack is built on hard ground, and bolted to a heavy brick foundation. The motion, therefore, gives the wave distortion of the solid earth, a motion of 6 feet at the top corresponding to a wave distortion of one-twenty-fifth part of the radius, or 2° 3'.[1] If the stack be regarded as vibrating about its center of gravity, the angle will be about half as large. These figures correspond to the distortion of the earth's level surface produced by the passage of the earthquake waves thru the rocky crust."

[1] This appears to involve the assumption that the stack was rigid, which is inconsistent with the described corkscrew motion. A. C. L.

Other observations mentioned by Professor See which are indicative of the intensity of the shock are the agitation of the water which was thrown into sharp cones, and filled with bubbles due to the escape of gases from the underlying mud; the shaking of trees and telegraph poles as by a storm; the fright noticed in all persons and animals; the throwing down of unstable objects; the raising of dust from the ground, and the formation of a mist in a few places. The motion was not so violent that one could not stand, yet during the violent part of the disturbance walking was difficult. All objects had a hazy outline, owing to the rapidity of motion, and it is said that persons presenting this aspect offered a comical sight to the beholder. The forests were agitated as by a violent wind, and at first the motion of the trees was ascribed by some marines on watch to a rising storm.

Vallejo Junction (T. J. J. See). — This station is just across the straits from the southeastern end of Mare Island and has only a few houses, the injury to which was not at all considerable. The intensity here was about the same as at Mare Island and Vallejo, as might have been expected from the proximity of these places.

St. John's Quicksilver Mine. — At the St. John's Consolidated Quicksilver mine near Vallejo, the following observations are recorded by Mr. Alphonso A. Tregidgo, manager of the mine. The note is of special interest as this is the only case in which underground disturbances have been observed in mines as a result of the earthquake of April 18:

We felt the shock about 5^h 15^m A. M., first north and south, and then east and west. We are working only two shifts, and as the night men "come off" at 4 A. M., there were no men in the mine when it occurred.

Our main tunnel is 1,135 feet in from the mouth. It cuts the lode 367 feet below the croppings, and crosses N. 3° 30′ E. At the end of this tunnel the old shaft was sunk 230 feet deep (vertical). The first 130 feet was thru the lode, the remaining 100 feet being in the "foot" or west wall, the lode going down to the east of the shaft. Within the year preceding the earthquake a new shaft was sunk which this main tunnel intersects 500 feet nearer its mouth, 160 feet below the surface. Right at this point the effects of the earthquake appear in the tunnel. The posts of the sets were "snapt off" about 8 inches from the bottom, and forced north for several sets. Our tunnel is timbered thruout 8 × 8, sets 4 feet apart. The old shaft timber sets dropt on the east side from 2.5 to 3 feet. This shaft is double compartment. The wall plates are north and south, and end pieces east and west. Carrying the ends with them, the east wall plates dropt to the 180-foot level, so that all the sets above that level are now 2.5 feet low on the east side. (From a point 1,125 feet in the tunnel the center of this shaft is located 22 feet 5 inches E. 17° S.) We have repaired the tunnel, but the shaft is beyond repair. As we connected our new shaft with the old shaft workings below the main tunnel level on April 16, just two days before the earthquake, we fortunately have no need of the old shaft for working purposes, tho it will be necessary to keep it open a while for ventilation. Strange to say, our new shaft was not damaged at all. It is timbered from top to bottom nearly 400 feet; sets 4 feet apart, close lagged. Not a lagging even moved. From a point 610 feet from mouth of tunnel, the center of new shaft bears S. 76° 30′ W. 14 feet 9 inches. No doubt considerable change has been caused by the earthquake in the old workings above the main tunnel, as our airways needed repairing in places.

Benecia (T. J. J. See). — The earthquake was decidedly more severe here than in Vallejo; 2 or 3 houses collapsed and half, or more than half, of the chimneys were thrown down. Major Benét, U. S. A., Commandant of the U. S. Arsenal, informs me that he reported to the War Department over 20 chimneys on the Government houses in the military reservation either thrown down or so injured that they had to be taken down. These houses all stand on solid high ground, none of them being on land made by the filling in of loose earth. Some of the Government buildings were cracked and otherwise injured, but on the whole the damage was not very extensive. In Major Benét's residence the furniture was considerably deranged, books were thrown down, bric-à-brac overturned and some of it broken. Such objects as dishes were frequently shaken off the shelves and crashed upon the floor.

At the entrance to the Arsenal grounds, the Gate House, used for the guard, is a round tower about 12 feet in diameter, made of brick and lined with a wooden ceiling. It was

built some 40 years ago, on a well-laid foundation going down to bedrock, which here underlies hard ground; yet the brick walls were badly cracked on every side. This guard-house stands on a high terrace, and the lower grounds appear to be alluvial deposits of the river.

In other parts of Benecia, brick houses built on hard ground were occasionally cracked. The town is somewhat spread out, some of it resting upon the alluvium near the river, the rest extending back over high rolling ground similar to that at the Arsenal. On the alluvial land the shaking was naturally most disastrous. A frame building near the water-tank, used for a saloon, collapsed; and a large cannery was so damaged that most of it had to be taken down. The water-pipe for the city was temporarily broken.

SACRAMENTO VALLEY.

Red Bluff, Tehama County. Population 2,750. (G. L. Allen.) — The earthquake awakened most sleepers. Quite a number of clocks were stopt. The chandeliers were caused to move considerably and in all directions. The tall head of a bed slammed against the wall, frightening the occupants. A lady tried to get up to keep an electric-light bulb, which was swinging violently, from striking a stove-pipe 2 feet distant from the cord; but she became dizzy and had to return to bed. The bulb did not strike the pipe. (J. H. Smith, Weather Bureau Observer.) No objects were overthrown, but hanging objects were caused to swing considerably. There was but one rather sharp jar, or shock, the direction of which is unknown. The inhabitants of the town were not unduly alarmed.

Corning, Tehama County. Population 1,000. (B. D. Wilkinson.) — I was awakened by what was at first thought to be wind moving the building; then I felt the bed and the building apparently roll in waves. Hanging electric lamps swung from south of east to north of west. Open doors swung for about half a minute.

Chico. Population 2,640. (W. M. Mackay.)—The shock here was quite pronounced, but not sufficiently so to do any damage. No chimneys were broken; nevertheless every house shook violently. I was awakened by the rattling of the weights in the windows. More than half the people interviewed say that the noise awakened them. Numerous clocks stopt, but no glassware or crockery was reported broken. In Chico Creek, adjoining the town, splashes on the bank indicated that there had been a violent commotion of the water. In places the water had been thrown several feet. The water-tank at the gas works was so disturbed as to cause the water to flow into the main, necessitating the pumping out of the main before service could be restored.

(E. Meyhew.)—I was in bed awake at the time of the shock. The motion was from north to south, and appeared to come in two waves, with an interval of about 6 seconds. The disturbance lasted about 15 seconds all together. It made windows rattle, and chandeliers and electric-light bulbs suspended by cords were caused to swing. It stopt 2 clocks in my store, one hanging on a southwest wall and the other on a southeast wall. All other clocks in the store continued going. A rumbling sound was heard thruout the disturbance.

Willows. Population 895. (A. W. Sehorn.) — The motion increased until the weights in the window-frames rattled considerably; trees swayed back and forth as in a hurricane for about 30 seconds, gradually diminishing. The movement appeared to be northeast to southwest, and was strongest near the middle. The clock was stopt, and the bed felt as if some one were pulling it. Chimneys were not injured. A rumbling noise preceded the shock.

Mr. G. K. Gilbert made a trip into the section of the Coast Ranges lying between the Clear Lake district and the Sacramento Valley. His purpose was to verify the report of a large rift said to have been made in St. John's Mountain by the earthquake. The rift was not found, tho sought for to the summit of the mountain; and the descriptions of it as an opening 10 feet wide by 20 feet long indicate that it is something quite different from

the ordinary manifestation of earthquake violence. The people at the base of the mountain were incredulous as to the existence of the crevice and especially as to its creation at the time of the earthquake.

As an outcome of this trip, Mr. Gilbert contributes the following note on the intensity of the earthquake shock at various points in the territory visited.

At *Williams* (population 500) the shock was strong enough to awaken people but not to throw down chimneys. It is said that small cracks were made in the walls of the hotel, a brick building. The intensity was about the same at Maxwell, population 300; Leesville; and Stony Ford, population 100. At Fouts Springs, 10 miles west of Stony Ford, only a few persons recognized the jar as due to an earthquake, and its identification was questioned by others until the news of the San Francisco disaster reached the place. As Stony Ford and Fouts Springs are near the east and south bases of St. John's Mountain, it is probable that the mountain was not severely shaken.

Elk Creek, Glenn County. Population 200. (P. E. Friday.) — The shock was very light. Some people heard windows rattle and noticed open doors swing slightly.

Colusa. Population 1,441. (Mrs. S. L. Drake.) — There was nothing overthrown, but water slopt from the tanks of the water-works on the north and south sides. The shock was so slight that only a few persons noticed anything more than a shaking, as tho some one had hold of the bedstead.

(E. S. Larsen.) — Many sleepers in Colusa were awakened, and some clocks were stopt, but there was no damage to chimneys and no glassware was broken. Window-frames in stores were in some instances displaced so as to leave a crack. Few cracks in plaster are reported. There is a general agreement that the vibrations were strong but slow and swinging. There is a fair agreement on the east and west direction for the vibrations. The jeweler had three pendulum clocks on the wall facing north. None of them stopt.

(Fred Roche.) — The shock in the central part of Colusa County lasted over a minute. There was only one continuous disturbance, but its intensity was strongest in the middle part. It caused windows to rattle, the bed to move, and hanging objects to swing, and overthrew some ornaments, but did not affect chimneys.

Meridian, Sutter County. Population 500. (T. F. Taylor.) — Two shocks were felt, the second being the stronger. No objects were overthrown.

Marysville, Yuba County. Population 3,497. (R. F. Watson.) — I was indoors, standing on the floor and stooping over when I felt quite a distinct tremulous motion for about 10 seconds before the main shock, causing a dizzy feeling. The shock itself started rather heavy and was jerky; it then became lighter until the second part of the shock came, with a rocking motion. The movement of the floor tipt me toward the southeast. No noise was heard. Windows and chairs rattled; electric-light bulbs suspended by cords first vibrated like a pendulum and then described a circle; and the pendulum clock stopt.

(A. B. Martin.) — The shock was sufficiently intense to arouse people from sleep, but no chimneys were broken nor was property injured.

Yuba City, Sutter County. Population 600. — The earthquake was generally felt; some sleepers were awakened and some clocks stopt. Movable objects were shaken. Water in horse-troughs was thrown several feet in an east and west direction in two cases, the troughs being oriented north-south and east-west respectively.

Black's Station, Yolo County. Population 300. (S. P. Cutter.) — No objects were overthrown, but hanging objects were caused to swing in a circle. There were 2 maxima, of which the first was the stronger; and a vertical movement was felt.

Knight's Landing, Yolo County. Population 500. (L. T. Shamp.) — While no large objects were overturned, small ornaments were thrown in all directions, and the shock was violent enough to stop several clocks. There was more than one maximum, tho the first was the strongest. The water in the Sacramento River rose to a height of 3 to 4 feet in long sweeping swells.

Lincoln. Population 1,061.—Clocks were stopt.

Fairoaks, Sacramento County. Population 300. (L. M. Shelton.) — There was one straight shake, which was very light. People scarcely knew there was an earthquake.

Sacramento. Population 29,282. (J. A. Marshall.) — I was awakened by my wife's remark that she believed we were having an earthquake. Thus aroused, I lookt up and the chandeliers seemed to be oscillating several inches in an eastward and westward direction. This continued, together with the rattling of the window weights in their boxes, for about a minute, during which time we arose and observed and verified the phenomena. The oscillation slowly decreased, and ended in two considerable jars, with appreciable intervals between. The clock on the mantelpiece facing westward stopt. It is, I think, so constructed that it would not have stopt had the vibration been northward and southward. The shock here would grade V, Rossi-Forel scale; or, more properly, between V and VI; but there was no breakage. Another slight shock occurred soon after 8 A. M., April 18, and a more noticeable one at $3^h\ 25^m$ P. M., April 19, of about grade III; the motion in this case seemed to be north and south.

(E. C. Jones.)—The damage at the gas plant was very slight. The gas-holders rocked to such an extent that considerable water was thrown out of the tanks, and the seals of the holder sections were partially emptied, allowing gas to escape. No damage was done to the manufacturing apparatus nor to the street mains.

(Hiram Miles.)—I was looking at the clock when the shock commenced. It lasted 2 minutes and 17 seconds, the first half being oscillatory and the second half a tremor. The movement was decidedly northwest to southeast.

(Charles A. Hendel, C. E. and M. E.)—I was on the second floor of the Western Hotel. I jumped out of bed, opened the door, and placed a chair against it, so that it would not close on me while I was dressing. I had to hold on to the bed to get drest. The oscillation appeared to me to be like the shaking of a mouse or a rat, by a cat.

Galt, Sacramento County. Population 350. — The shock lasted 45 seconds.

Ione, Amador County. Population 806. (J. F. Scott.) — The shock awakened and alarmed people. There were two distinct maxima, of which the second was the stronger. The direction of movement was north. No objects were overthrown.

(Wm. Randall.) The vibration was gentle but of such amplitude as to attract unusual attention. It was seemingly in a north and south direction, and estimated to continue for 20 or 30 seconds.

Suisun, Solano County. Population 625. (Mr. Sheldon.)—The shock awakened nearly every one, threw 2 or 3 chimneys, and damaged perhaps 25 per cent of the chimneys so that they required repairing. Masonic Hall had a few bricks thrown from an ornamental arched window. The plaster was much cracked, but there was no serious damage. Thruout both Suisun and Fairfield considerable plaster was cracked and even thrown down; a few bottles were thrown from shelves; a large proportion of the clocks were stopt; and a few windows were broken. There was no agreement as to direction. Vibrations were long and rolling.

Elmira, Solano County. Population 317. (E. S. Larsen.)—Most sleepers were awakened but no damage was done. There are few brick chimneys, and none of them was thrown or cracked. No plaster was thrown down and no windows were broken. As there are only a few small houses in the town it is rather difficult to make an accurate comparison; but the shock was probably considerably less severe than at Suisun, and slightly less than at Vacaville.

Vacaville, Solano County. Population 1,220. (E. S. Larsen.) — About 12 chimneys were cracked or thrown, some plaster was cracked, most clocks were stopt, and probably all sleepers were awakened. Things were very seldom thrown from shelves. There is a general impression that the vibrations were east and west, and that they were of a slow rocking nature.

Esparto. Population 200. — Clocks were stopt.

Capay, Yolo County. Population 200. (E. S. Larsen.) — Sleepers were awakened and milk slopt over in pans, but no chimneys were thrown, no windows were broken, and no clocks were reported stopt.

(S. Schwak.) — There was one continuous shake from northeast to southwest, resulting in the spilling of milk from pans. No objects were overthrown.

Guinda, Yolo County (J. Jacobsen). — There was one continuous shake for about 25 seconds, the apparent movement being from northwest to southeast. A vertical upward motion was also experienced. Nothing was overthrown.

Rumsey, Yolo County (J. M. Morrin). — The movement was from southeast to northwest. There were 2 maxima, the second being the stronger.

(E. S. Larsen.) — There was no damage whatever to buildings, but most sleepers were awakened. The vibrations were long and gentle.

Woodland (E. S. Larsen). — Most sleepers were awakened, but no chimneys were thrown and no glass was broken. A few clocks were stopt, one of which faced east. All agree that the vibrations were slow and gentle and of a rocking nature. Mr. J. L. Spohn states that he was awake at the time, and observed an electric-light globe hung by a cord. At first the globe vibrated east and west, and then had a rotary motion.

Davisville (E. S. Larsen). — Most sleepers were awakened. One man reports 2 or 3 chimneys cracked, but every one else denies this. Some plaster was cracked and doors were jammed so that they required resetting. No glass was broken. Various observers report vibrations from east to west or north to south, but they do not agree. All report the vibrations long and slow.

Maine Prairie, Solano County (Mrs. A. Rattike). — No damage resulted from the earthquake. A gentle swing was experienced, the motion of which was from southwest to northeast, as evidenced by waves generated on the surface of the water on the overflowed land.

Rio Vista, Solano County. Population 682. (J. C. Stanton, C.E.) — The character and effects of the shock are described in a note published in the Climatological Report of the U. S. Weather Bureau for April, 1907, as follows:

> The shake was very severe. It commenced with a number of quite long vibrations from northwest to southeast and wound up with the figure 8 motion which often accompanies seismic disturbances. It was quite difficult for persons to maintain their footing; but strange to say, nothing was thrown down or overturned, which may be attributed to the gyrating motion. The duration was about 30 seconds, and I am convinced that had it continued 30 seconds longer hardly a house would have been left standing in town. Some lumber piles were thrown down in a lumber yard situated upon a pile wharf, where the disturbance seemed worse than anywhere else; and the water-tower, 60 feet in height, consisting of 2 large tanks containing 100,000 gallons, was seen to sway violently.

Collinsville, Solano County. Population 300. (Joseph Antonini.) — Collinsville is on the peat of the tule land, with hard clay 2 feet below the surface. The largest building in town, a hotel built on piles, was totally wrecked. Chimneys and water-tanks were overthrown. The movement was east.

NORTHERN SIERRA NEVADA.

Butte County. — At John Adams, population 75, and at Berdan, a slight trembling of the earth is reported. At Paradise, population 100, Mr. F. W. Day reports that hanging objects vibrated violently, and that a "sinking sensation" was experienced. At Stanwood the shock, according to Mr. S. E. Rowe, was very slight and noticed by very few people. At Honcut, population 100, a slight shock is reported by Mr. D. B. Robb.

Quincy, Plumas County. Population 516. (L. A. Barrett.) — The shock was heavy enough to awaken a few people, but was not felt by the majority of the inhabitants. Mr.

J. W. Street, watchmaker, reports that his clock stopt in consequence of the shock. This was the only clock in town that stopt.

Other points in Plumas County at which the earthquake is reported to have been felt as a slight shock are Greenville, population 640; Taylorsville, population 130; Kettle; and Beckwith, population 100. At La Porte (population 300), Mr. Oscar Freeman says: "The shock was very light. There were but few persons in town that felt it, perhaps a dozen. It made the house creak as would a sudden gust of wind, set the hanging lamp swinging, and seemed to have a twisting or circular motion, as near as I could judge."

Sierra County. — Slight shocks are reported to have been felt at Table Rock, by John K. Walls; and at Allegheny (population 200), by W. A. Clayton. At Loyalton (population 100), Mr. J. J. Miller reports a confused shock in three parts. An electric bulb hanging from the ceiling was caused to swing in a circle. At the west side of Sierra Valley, in the tule land, the quake was more severe, and caused dishes to rattle and loose objects to sway.

Nevada County. — A slight shock is reported at the following points: Fernley, by G. V. Robinson; French Corral (population 150), by W. E. Moulton; Grass Valley (population 4,719), by C. W. Kitts; Chicago Park, by E. F. Sailor; North Columbia, by Mrs. C. J. English; Washington (population 500), by J. H. English; and Floriston, by W. I. Sunburnt. At Boca (population 50), Mrs. A. E. Daswell reports that the shock comprized only one movement, which lasted about one minute and was strong enough to make an electric-light bulb swing. At Truckee (population 1,600), W. S. T. Smith reports that the shock was felt by a number of people. Windows rattled, hanging objects swung, and a clock stopt. No objects were overthrown.

Placer County.—According to the reports received, the shock seems to have been less generally felt than to the north or south. A slight shock, noticed by few people, is reported to have been felt at Newcastle, population 600; Auburn, population 2,050; Yankee Jim, population 150; and Emigrant Gap, population 60.

Georgetown, Eldorado County. Population 400. (C. M. Fitzgerald.) — The shock was distinctly felt by most people, and the disturbance was sufficient to awaken those not already up. No objects were, however, overthrown. The movement was decidedly from north to south. The duration was estimated at 30 seconds.

Nashville, Eldorado County. Population 50. (J. C. Heald.) — But few people felt the quake. Many spoke of some disturbance having awakened them. The few who were awake at the time felt the jar, but did not know what it was. The shock was felt somewhat more distinctly to the north and south of Nashville.

Pino Grande, Eldorado County (W. E. Borham.) — Few felt the shock, which was light. Hanging objects swayed back and forth. No objects were overthrown.

Drytown. Population 300. (Allen McWayne.) — The shock was felt by only one or two people in town.

Milton, Calaveras County. Population 200. (J. H. Southwerk.) — The shock was distinct. There were 2 maxima, and the second was probably the stronger. The direction of movement was east and west. Mr. S. D. Hildebrand, who was on the bottom-land of the Calaveras River, 3 miles west, felt a more violent shock, but no damage was done.

Railroad Flat, Calaveras County. Population 200. (R. B. Knox.) — Mr. Knox was awakened by a smart shock which shook his bed for nearly a minute.

West Point. Population 266. (Mr. Balsley.) — A pail of water two-thirds full slopt over; pans rattled, and the clock was moved on the wall. The shock moved Mr. Balsley's bed from side to side, southwest to northeast.

A shock was reported, without further details as to its effects, at Campo Seco; Esmerelda; Mokelumne Hill, population 575; Nassau, population 50; North Branch; and Vallicita, population 500.

Gold King Mine (Henry Seeman). — Near Gold King Mine, sec. 26, township 6 N., Range 14 E., a moderate shock was felt. This was, however, not noticed by any of the 15 persons at the mine, less than 0.25 mile away, nor by the night shift in the mine, and awakened no sleepers.

Blanchard, Tuolumne County (Mrs. C. E. Blanchard). — One chimney was damaged slightly, but the shock otherwise did no damage. The shock was light, tho generally felt in the surrounding country.

Columbia, Tuolumne County. Population 500. (J. W. Pitts.) — The shock was so light that those asleep did not feel it and did not wake up. Mr. Pitts and others who were up felt a slight shock and motion from north to south.

Sonora, Tuolumne County. Population 1,922. (J. E. Coover.) — The movement seemed to be an easy rocking one, free from jerks, with considerable amplitude. The earthquake was in full swing when Mr. Coover awoke; it held its maximum intensity for some moments, it seemed a half-minute, and then diminished gradually. A pendulum clock stopt.

Tuolumne, Tuolumne County (Capt. J. T. Thompson). — In the Turnback Inn, a large frame structure, some window glass was crashed diagonally, and sleepers were generally awakened. The movement was oscillatory and seemed to be east and west. At the Grizzly Mine, in the bottom of Tuolumne Canyon, about 1,000 feet below the town of Tuolumne, the shock was not felt.

Jupiter, Tuolumne County (Cornelius Quinlan). — Was awakened by the shock at 5^h 14^m A. M., and experienced a sliding back and forth from north to south for about 20 seconds after awakening.

Sequoia, Tuolumne County (Mr. Crocker). — Two prolonged light shocks were felt, of the nature of a pronounced tremble. Some members of Mr. Crocker's family did not feel it.

Yosemite Valley. — A slight shock was felt.

DISTRIBUTION OF APPARENT INTENSITY IN SAN FRANCISCO.

By H. O. Wood.

INTRODUCTION.

In presenting the results of this study, the subject-matter has been taken up as follows: First, brief mention is made of the physiographic features of the city. Map No. 4, of the atlas accompanying the report of the Commission, shows the location of the city and its physiographic environment, also a segment of the Rift and of the fault on which the earthquake of 1906 was generated, and the position of a similar fault where the shock of 1868 originated. The city lies between these two zones of faulting. Then follows a note on the general geology of the region, illustrated by a geological map, No. 17 of atlas, prepared by Professor Andrew C. Lawson, on which is shown the areal distribution of the more important rock formations and of the districts of "made" land. Then comes the description and classification of typical destructive effects examined in the field. An intensity scale is discust, and its relationships to the Rossi-Forel and Omori scales are determined as well as possible. By critical comparison with Omori's scale, approximate values are fixed for the grades in terms of acceleration. Illustrating this discussion, map No. 19 of the atlas, showing the areal distribution of intensity in terms of an especially devised scale, presents graphically the results of the investigations in the city. The methods employed in the preparation of the map are set forth; also the manner in which the intensity scale was utilized. In map No. 18 are shown several geological cross-sections with corresponding intensity profiles. As vertical coördinates of the latter, values of the grades determined approximately in terms of acceleration were utilized.

Following the general discussion of the intensity is a detailed description of the evidence which characterized various localities and determined the intensity grades ascribed to them.

Next are discust details of evidence in the localities where very high intensity prevailed, which are of general interest owing to the suggestions they offer, the problems they raise, or the warnings they proclaim.

PHYSIOGRAPHY.

The San Francisco peninsula rises with bold relief from the level of the sea to hill summits varying in altitude between 100 and 1,800 feet, with the broad Pacific to the west of it, the waters of San Francisco Bay to the east, and the Golden Gate on the north. Southward, trending slightly east, the peninsula runs for several miles, merging finally with the hills of the Santa Cruz Range which mark the eastern limits of the Santa Clara Valley. On the western shore, promontories such as Point Lobos, Mussel Rock, San Pedro Point, and Montara Point, where rock-cliffs rise out of the surf, alternate with stretches of smooth beach line. At the north, the hills come down to the shore, forming rocky points: Point Lobos, where the Cliff House stands; Fort Point, marking the narrowest part of the Golden Gate; and the minor promontories of Black Point and Telegraph Hill farther east. The eastern shore is marked by prominent rock ridges extending out into the Bay, while between these, reaching well back into the hills, are sharply limited valleys cut down to the level of the sea and filled with deep deposits of alluvium, thus forming a gently sloping floor from which the hills rise abruptly. Before the building of the city, tide marshes with their little tidal creeks occupied the floors of these valleys, near their mouths.

The most important of these is the relatively large Mission Valley, opening into the Bay between Rincon Point and Potrero Point and extending back westward and then southward, with a minor fork to the northwest, fully a quarter of the way across the peninsula. Mission Creek, with its lagoon and contiguous marsh, before it was filled to provide street and building sites, extended from the Bay shore around the northern extremity of the hills of the Potrero. Another long narrow marsh occupied a part of the floor of Mission Valley, stretching eastward from the present site of the Post-office building for several blocks, and then turning southward to the old Bay shore. This marsh also has been filled to provide building sites. Another dominant valley is that of Islais Creek, stretching back to the southwest between the hills of the Potrero and those of Hunters Point. This valley is outside the city proper.

The city and county of San Francisco occupy the northern end of the peninsula, bounded on the south by an arbitrary east-west line some 7 miles south of the Golden Gate. The city, properly speaking, occupies the northeastern third of this area, covering the summits and flanks of the sandstone hills known as Telegraph Hill, Nob Hill, and Russian Hill, on the north; and other unnamed summits on the west. It covers also the floor of Mission Valley and reaches well up on the flanks of the hills which culminate in the center of the area. On the outskirts of the city proper, except in the southwestern part, are small detached groups of dwellings in the hills or on the sands.

Market Street is a broad thorofare running southwestward from the Ferry Building and the wharves, at the northeast corner of the city, thru Mission Valley to the flanks of the high hills in the center of the area. About the lower part of Market Street is the commercial center of the city. The City Hall, situated about 1 block north of this broad highway, and about 12 blocks southwest of the Ferry, was not far from the center of the city proper.

The zone of faulting where the recent earthquake had its origin past under the sea from a point near the head of Bolinas Lagoon, 12 or 15 miles northwest of the Golden Gate, to a point half a mile north of the little headland of Mussel Rock, about 8 miles south of Point Lobos. The map, No 4, shows its location.

The entire area of the city and county is east of the fault-zone. The southwest corner of the area is less than a mile distant from it. The vicinity of the Ferry Building, at the foot of Market Street, was the most remote of any point in the whole area, being between 9.25 and 9.75 miles away. The site of the City Hall is from 7.5 to 8 miles from the fault. The Cliff House, at Point Lobos, the most western point of the area, is about 3 miles east of it. Fort Point lies between 5.75 and 6 miles east of it. Potrero Point and Hunters Point, as well, are about 8.5 miles from the fault. Hunters Point is the most easterly point in the district.

GEOLOGY.

It is desirable to insert here a brief abstract of the geology of the northern part of the San Francisco peninsula, for it will appear that the effects produced by the earthquake were largely influenced by the character of the underlying formations. Map No. 17 shows the distribution of the geological formations at the surface. It shows also the areas of "made" land. These areas were determined by plotting the shore line shown on the accurate chart published in 1853 by the U. S. Coast and Geodetic Survey, upon the latest accurate chart of the same bureau. In these districts the materials forming the surface have been transported to their present position by human agency. The depth or thickness of this "filled" stratum is variable and, for the most part, not definitely known.

A little study, comparing the areas of rock with the topographic contours, shows that all the hills are of firm rock, mostly coated with a veneer of soil and vegetation, but frequently outcropping at the surface. In general, their lower flanks are more and more thickly covered with loose sand and alluvium the nearer approach is made to the floor of

the valleys or the districts of sand-dunes. At the lower levels such loose materials cover the whole area very generally. The thickness of these strata must be notably variable, considering the uneven configuration of the rock surface where it emerges from this mantle, since it is probably no less irregular beneath the covering. Very little information is available concerning the depths to which these uncemented materials extend. A well at the United States mint is about 176 feet deep and is believed not to have reached bedrock. A boring that was sunk at the corner of 7th and Mission Streets past thru sand and clay to a depth of 264 feet, but did not reach bedrock. In general the sands and clays fill deeply the major valleys, Mission and Islais. The minor northwest fork of Mission Valley, called Hayes Valley along its lower part, is probably less deeply filled. This is certainly true of its upper reaches, to which, in this report, the name Upper Hayes Valley is applied. Minor valleys and gullies all over the area have thin coverings of sand and alluvium which quickly thin out where the slopes of the hills begin to rise steeply.

From the ocean inland for a considerable distance extends an area covered with sand-dunes. This district is limited irregularly at the east by the contour of the hills. The sands form a thick mantle near the ocean shore, which becomes thinner and thinner as it rises upon the lower flanks of the hills. As in the case of the materials filling the valleys, the rock floor upon which the sands rest is probably very irregular.

Of the hills, the northern ridge is carved out of the firm sandstone of the Franciscan series. Along this ridge are the summits of Telegraph Hill, Nob Hill, and Russian Hill, with other unnamed hilltops to the west, separated from each other by little saddle-like depressions in the surface. The outlying summits of Black Point and Rincon Hill appear to belong genetically to this ridge. This body of sandstone abuts on the west against a mass of serpentine, which forms a narrow range of hills stretching southeastward across the peninsula from Fort Point to Potrero and Hunters Points.

This serpentine is intrusive in the firm Franciscan rocks, chert, and sandstone. The southwestern boundary of the serpentine in the vicinity of Fort Point is determined by a fault which has a throw of about 1,000 feet. This fault may possibly extend quite across the peninsula along the southwestern limits of the serpentine, but the field evidence does not warrant any definite statement. The fault movement occurred so long ago that the present land surface gives no unequivocal indication of its position. Mission Valley cuts across the body of serpentine, separating the northern hills from the southern group. The northern group rises along the western boundary of Hayes Valley.

The central and southern hills, and the ridge at the northwest of the city, are carved intricately from firm Franciscan rocks, sandstone, and chert, commingled with minor bodies of irruptive rock of basaltic character.

The hills of the more remote southwest corner of the city and county are of softer rocks of more recent geological origin — sandstones and shales of the Merced formation. These are relatively little cemented. Readers interested in a more complete account of the geology should consult the detailed report on this peninsula.[1]

DESTRUCTIVE EFFECTS AND INTENSITY SCALES.

To some extent the earthquake caused damage to buildings and other structures in all parts of the city and county of San Francisco. The whole area was decidedly within the destructive zone. Still, over a large part of this area, far the larger part, the damage was slight both in amount and character. Almost everywhere chimneys were thrown down or badly broken, but in a few small localities most of the chimneys withstood the shock. Some probably were unhurt. Plaster on walls and ceilings was very generally damaged. So, probably, were frail partition walls and chandeliers, crockery and fragile household furnishings. Such effects were typical of large sections of the city. There

[1] The Geology of the San Francisco Peninsula, by Andrew C. Lawson, 15th Ann. Rept., U. S. G. S.

were relatively small districts, however, in which brick and frame buildings of ordinary construction were badly wrecked or quite destroyed. Pavements were fissured, buckled, and arched. Sewers and water-mains were broken. In places, portions of streets were moved laterally several feet out of place. Well-ballasted street-car tracks, equipped with 8, 10, or 11 inch rails, were arched and flexed or thrown into shallow wave forms. The whole land surface, sometimes for several blocks together, was deformed into shallow waves of irregular extension, length, and amplitude. Effects of this degree of violence were pretty closely confined, as has been stated already, to areas of "filled" or "made" land. Such characterize, therefore, only a small portion of the city; but, as it happens, areas of commercial importance and of special interest for the scientific purposes of this inquiry. In consequence they will require a relatively large share of attention.

These destructive effects vary in degree from place to place thru the whole range between the extremes cited. In some cases this variation is best shown by the character of these effects; again by the frequency of their occurrence. The change from strong effects to weak sometimes takes place rather abruptly within the distance of a block or two, or less. Commonly the localities where very violent effects were produced are themselves pretty sharply limited. In such cases, however, there is still a noticeable variation in the sort and amount of damage resulting at different points just outside their limits, along their peripheries. At other places the destructive effects change gradually thru a distance of several blocks.

This areal variation in the degree of damage indicates clearly a like variation in the intensity of the shock. The effects produced are the direct results of the intensity manifested, since where nearly all kinds of structures are to be found in all districts, of whatever intensity, such factors as the individual strength of the injured structures must practically cancel in the aggregate result. Consequently the destructive effects furnish a measure of the intensity, not very precise, it is true, but the best available, since no seismographic instruments were maintained in the city. By a classification of these effects different grades of intensity can be recognized and defined.

Several such classifications have been made by seismologists for this purpose. The best known of these is the Rossi-Forel intensity scale, which provides ten scale numbers. The first defines a shock just barely perceptible to a sensitive observer, or one recorded by a sensitive seismograph; the tenth, a great disaster. The four highest numbers of this scale, as republished by the present Commission in its Preliminary Report, are as follows:

VII. Violent shock, overturning of loose objects; falling of plaster; striking of church bells; some chimneys fall.

VIII. Fall of chimneys; cracks in the walls of buildings.

IX. Partial or total destruction of some buildings.

X. Great disasters; overturning of rocks; fissures in the surface of the earth; mountain slides.

The range of intensity in the city did not exceed these limits. Probably it did not reach the higher numbers recognized by the scale number X. In only a few small localities were the minimum values of scale number VII prevalent. It is easy to see, however, that this scale distinguishes its three upper scale numbers in vague terms, particularly with regard to effects likely to be produced in a modern city. For this reason it was found unsatisfactory for the investigations in San Francisco.

A scale of greater merit is that devised by Professor Omori, of Tokyo, given below:

No. 1. Maximum acceleration is 300 mm. per sec. per sec. People run out of houses; brick walls of bad construction are slightly cracked; plaster of some old dozo (godowns) shaken down; wooden houses so much shaken that cracking noises are produced; trees visibly shaken; water in ponds rendered slightly turbid in consequence of the disturbance in the mud.

No. 2. Maximum acceleration is 900 mm. per sec. per sec. Walls in Japanese houses cracked; old wooden houses thrown slightly out of the vertical; tombstones and stone lanterns of bad construction overturned; in a few cases changes are produced in hot springs and mineral waters; ordinary factory chimneys not damaged.

No. 3. Maximum acceleration is 1,200 mm. per sec. per sec. About one factory chimney in every four is damaged; brick houses of bad construction are partially or totally destroyed; a few old wooden dwellings and warehouses totally destroyed; wooden bridges slightly damaged; some tombstones and stone lanterns overturned; shoji (Japanese paper-covered sliding doors) broken; roof tiles of wooden houses disturbed; some rock fragments thrown down from mountain sides.

No. 4. Maximum acceleration is 2,000 mm. per sec. per sec. All factory chimneys are broken; most of the ordinary brick buildings partially or totally destroyed; some wooden houses totally destroyed; wooden sliding doors and shoji mostly thrown out of their grooves; cracks 2 or 3 inches in width, in soft or low ground; embankments slightly damaged here and there; wooden bridges partially destroyed; and ordinary stone lanterns overthrown.

No. 5. Maximum acceleration is 2,500 mm. per sec. per sec. All ordinary brick houses very severely damaged; about 3 per cent of the wooden houses totally destroyed; a few *tera*, or Buddhist temples, are thrown down; embankments severely damaged; railway lines slightly curved or contorted; ordinary tombstones overturned; *ishigaki*, or masonry walls, damaged here and there; cracks 1 to 2 feet in width produced along river banks; water in rivers and ditches thrown over the banks; wells mostly affected with changes in their waters; landslips produced.

No. 6. Maximum acceleration is 4,000 mm. per sec. per sec. Most of the *tera*, or Buddhist temples, are thrown down; 50 to 80 per cent of the wooden houses totally destroyed; embankments shattered almost to pieces; roads made thru paddy fields so much cracked and deprest as to stop the passage of wagons and horses; railway lines very much contorted; wooden bridges partially or totally destroyed; tombstones of stable construction overturned; cracks a few feet in width formed in the ground, accompanied sometimes by the ejection of water or sand; earthenware buried in the ground mostly broken; low grounds, such as paddy fields, very greatly convulsed both horizontally and vertically, sometimes causing trees and vegetables to die; numerous landslips produced.

No. 7. Maximum acceleration is much above 4,000 mm. per sec. per sec. All buildings except a very few wooden houses are totally destroyed; some houses, gates, etc., projected 1 to 3 feet; remarkable landslips produced, accompanied by faults and shears of the ground.

In the foregoing scale, in addition to these definitions by destructive effects, it will be noticed that a range of values for the *acceleration* is assigned to each scale number. These acceleration values have been tested experimentally by Professor Omori, and found accurate within narrow limits. Consequently it is called an *absolute* scale. It is the best intensity scale yet proposed. Since, however, it is defined in terms of damage produced upon Japanese structures, it would require constant critical interpretation in use in an American city. For this reason, it is believed to be not so well adapted to the purposes of this investigation as the scale proposed below. This is especially true since the values of the acceleration necessary to produce the destructive effects encountered here have not been determined by experiment. A use of the absolute scale would, therefore, pretend to an accuracy not attained with any certainty. The following scale will be referred to as the San Francisco scale:

Grade A. Very violent. — Comprizes the rending and shearing of rock masses, earth, turf, and all structures along the line of faulting; the fall of rock from mountain sides; numerous landslips of great magnitude; consistent, deep, and extended fissuring in natural earth; some structures totally destroyed.

Grade B. Violent. — Comprizes fairly general collapse of brick and frame buildings when not unusually strong; serious cracking of brick work and masonry in excellent structures; the formation of fissures, step faults, sharp compression anticlines, and broad, wave-like folds in paved and asphalt-coated streets, accompanied by the ragged fissuring of asphalt; the destruction of foundation walls and underpinning structures by the undulation of the ground; the breaking of sewers and water-mains; the lateral displacement of streets; and the compression, distension, and lateral waving or displacement of well-ballasted street-car tracks.

Grade C. Very strong. — Comprizes brick work and masonry badly cracked, with occasional collapse; some brick and masonry gables thrown down; frame buildings lurched or listed on fair or weak underpinning structures, with occasional falling from underpinning or collapse; general destruction of chimneys and of masonry, brick or cement veneers; considerable cracking or crushing of foundation walls.

Grade D. Strong. — Comprizes general but not universal fall of chimneys; cracks in masonry and brick work; cracks in foundation walls, retaining walls, and curbing; a few isolated cases of lurching or listing of frame buildings built upon weak underpinning structures.

Grade E. Weak. — Comprizes occasional fall of chimneys and damage to plaster, partitions, plumbing, and the like.

This scale obviously is simply a classification of the phenomena observed. It defines as many grades as the facts seemed to express in this field. It is more finely subdivided than the Rossi-Forel scale and, for conditions in a modern city, the definitions are better framed. It has less intrinsic merit than the Omori scale, for both scales cover a similar range of destructive effects, but the subdivision is finer and more evenly spaced in the case of the Omori scale. Also the grades of the San Francisco scale can not be fixed by values of the acceleration, except approximately by comparison with the absolute scale. The fact, however, that it does not pretend to absolute values seems a point in its favor under the circumstances. And it is a practical scale for the phenomena dealt with.

Altho rigorous values can not be obtained by such means, it is desirable to subject the grades to careful comparison with the numbers of the Omori scale in order to determine reasonably close acceleration values for them.

A comparative study of the 3 scales is summarized diagrammatically in the accompanying table at the top of next page.[1]

Some of the effects which serve to define Grade A are weaker than the maximum effects defining No. 6 of the absolute scale; and nowhere, not even in the vicinity of the fault, were most buildings totally destroyed.

Grade B covers a wide range. Perhaps if the initial shock had been a little stronger; it could have been subdivided with some certainty.

Grades C and D cover each a slightly lower range of values than the scale numbers 3 and 2, to which they correspond most closely.

Grade E, as defined, is more narrowly limited than No. 1.

These values, despite their lack of precision, constitute the best approximation to an absolute measure of energy developed, for each grade of intensity, which it appears practicable to attain. There were no instruments of precision to record the character and amount of the motion of the shock, hence estimates of other sort than this seem difficult to make. The fact must not be lost sight of, however, that it is only an estimate, based upon the interpretation of a series of destructive effects produced in very variable media under variable conditions and then compared with a similar series of destructive effects produced in structures of a different sort, for which pretty accurate acceleration values had been determined experimentally.

[1] The definitions of the Omori absolute scale and the information about it are taken from the book on Earthquakes in the Light of the New Seismology, by Major C. E. Dutton.

Rossi-Forel Scale.	Omori Scale.	San Francisco Scale.	Acceleration mm. per sec. per sec.
	No. 7		
			4,000
		Grade A	
	No. 6		
			3,000
			2,500
10	No. 5	Grade B	
			2,000
9	No. 4		
			1,200
	No. 3	Grade C	900
8			800
	No. 2	Grade D	
			300
7	No. 1	Grade E	200

It may be perhaps well to point out that Grade D lies between Nos. VII and VIII of the Rossi-Forel scale. This grade characterizes the greater part of the city, as the intensity map shows. Grade B, equivalent to Nos. IX and X of the same scale, is characteristic of very small areas only. Grade A is not exhibited in the city proper.

Utilizing the San Francisco scale, intensity map No. 19 was prepared, which indicates the location and areal extent of the districts characterized by each grade of intensity. It presents graphically the results of the field work. In the field study, practically all of the city proper, including the large area devastated by fire, was thoroly traversed, excepting one or two isolated hilly localities where a brief examination showed no significant damage. Unbuilt districts were, of course, comparatively neglected, except where disturbances of natural objects were found or lookt for. Chimneys, buildings, streets, paving, curbing, sidewalks, car tracks, retaining walls, etc., were subjected to careful scrutiny, and such injuries as were observed were classified on the spot in terms of the San Francisco scale. The intensity indicated was recorded by a spot of color placed upon a field map of suitable scale (1,760 feet to the inch, or 1: 21,120). Many photographs were made, some of which appear as illustrations in this report.

Detailed field notes were made only when damage of unusual or striking character was encountered, or when it was perplexing. When effects were observed which seemed likely to be of value in analyzing the character of the earth motion, notes were made. Little indoor evidence was obtained or sought.

It will thus be seen that the field study, while adequate for the purposes in view, did not constitute an expert engineering investigation, dealing with specific details and location of damage. Frequently there was doubt as to what grade of intensity should be assigned to a given city block, because of conflicting or inadequate evidence in the field. This is particularly true of districts swept by fire, especially where the intensity was low; for most

of the effects which serve to define the lower grades were obliterated with the structures in which they were developed. Where buildings were sparsely distributed, it was often hard to determine what grade of intensity was developed, for the evidence was scattering and heterogeneous. Nevertheless, the map is a pretty faithful representation of the distribution of intensity, and quite justifies the scientific and economic conclusions of a general nature that are drawn from it here.

On the map, color in northwest-southeast bars (A, B, C, D, E) represents districts marked by unequivocal evidence. Continuous lines indicate the position of well-determined boundaries between areas affected by different grades of intensity. Color applied in northeast-southwest bars (a, b, c, d, e) represents districts in which the evidence was scanty or circumstantial; and dotted lines indicate the position of boundary lines which were determined but vaguely by the phenomena in the field.

DETAILED DESCRIPTION OF THE EVIDENCE BY LOCALITIES.[1]

No district designated upon the map as exhibiting intensity of Grade E, so far as the writer could find, exhibited any destructive effects of a more violent kind than the fall of chimneys. The really typical measure of intensity for these localities was the cracking and falling of plaster. Without exception, these are places where the firmly cemented bedrock of the Franciscan formations is either exposed directly or covered with a very thin mantle of soil. This lowest grade of intensity does not, by any means, characterize all places where the firm bedrock is exposed at the surface. It was rather developed on the summit portions of the rocky hills. The tops of Telegraph Hill and Russian Hill are districts in which a large part of the chimneys withstood the shock. This was also the case with the upper slopes of the chert hills about the head of Market Street, at the center of the area. Scarcely any injuries resulted on the hills of the Potrero; and one or two small serpentine hills just north of Market Street were likewise immune. Similarly, the Hunters Point serpentine ridge was subjected to a shock of low intensity; at least, a hasty survey pointed to this conclusion, tho the evidence was sparse and not thoroly examined. San Bruno Mountain, however, was about as near to the zone of faulting as Point Lobos, where most of the chimneys were thrown. Intensity of Grade D is believed, therefore, to have been developed upon the summit of San Bruno Mountain.

The general fall of chimneys, slight cracking of brick work, and such damage, denoting intensity of Grade D, characterizes the northeastern half, or possibly two-thirds, of the city and county, except in localities where special conditions, chiefly lithological, modify it. Districts of exposed bedrock on the flanks of the hills, and of sand and alluvium wrapped as a thin mantle about their lower slopes, exhibited this degree of damage. Consequently a large area was affected by this grade of intensity which does not, in general, require detailed discussion; no violent nor specially significant effects being produced. Where, however, the loose earth covering is thicker, the magnitude and frequency of damage increases. Market Street, between Second and Fourth Streets; Mission Street, between First and Third Streets; and Howard Street, between Second and Third Streets, together with the blocks in the neighborhood of Market Street on Montgomery and Kearney Streets, Grant Avenue, Stockton and Powell Streets, form a district in which the effects denote an intensity only a little short of Grade C. A large proportion of the buildings were excellent structures which individually withstood the shock well. In consequence, it was difficult to draw a line in this region between districts marked by broken chimneys and cracked brick walls, and those where more serious damage was certainly developed. The resistant character of the excellent buildings and the thoro obliteration by the fire of evidence produced in poor structures, render the determination of the intensity as Grade D somewhat doubtful.

[1] The streets referred to in these descriptions are shown on map 20 of the atlas.

In the blocks adjacent to Point Lobos Avenue and Clement Street, between First Avenue and Sixteenth Avenue, in the sand-dune district, damage — mostly of Grade D — was prevalent. This locality is the part of the city nearest to the seat of the disturbance, and the cover of sand which rests upon the uneven bedrock is unevenly thick; therefore irregular variations of intensity are to be expected. Nevertheless it is not easy to fix the boundaries between Grade C and Grade D in this part of the city.

Along Oak and Fell Streets, and the Panhandle Parkway from Broderick Street west, the intensity closely approaches Grade C without seeming quite to reach it.

Along Washington Street and its immediate vicinity, from Baker Street west to Spruce Street, on the crest of the sandstone ridge, the intensity is higher than for most other localities of exposed bedrock. Fallen chimneys and cracks in foundation walls were more prevalent than in most areas so situated.

On bedrock at Point Lobos, also, the effects indicate an intensity pretty close to Grade C, but this locality is nearer the fault than any other Franciscan outcrop save the western slopes of San Bruno Mountain.

We may say in general, therefore, that Grade D is the intensity developed on bare rock foundations, or on rock only moderately coated with soil, in the northeastern part of the city and county of San Francisco.

In the low lands of the valleys, and along portions of the water-front, the sand and alluvial deposits are thicker and the destructive effects were increased in magnitude and in prevalence; also thruout a large part of the sand-dune tract at the west, wherever evidence was obtained, increased intensity was found to prevail.

All over Mission Valley and Hayes Valley, including Upper Hayes Valley, brick walls were cracked and some gables and walls actually fell. Buildings placed on weak underpinning were frequently displaced slightly from the vertical. In a few cases, weak frame dwellings collapsed as a result of the giving way of weak foundation structures. Most chimney stacks were broken. In no part of this large district was evidence of this kind lacking, altho the majority of the structures were fairly substantial frame dwellings, and were of course not seriously damaged. There was much indoor damage, but no investigation of this was undertaken.

At the outer margin of this area, marked by an intensity of Grade C, the destructive effects were weaker, indicating an intensity just above Grade D. Where the district adjoins localities which suffered a still severer shock, the damage was of greater magnitude and more prevalent. Besides this gradation there were, within the limits of the district, several little localities where the characteristic destructive effects were conspicuously numerous.

In the neighborhood of O'Farrell Street, between, say, Mason and Taylor Streets, brick work was sadly cracked. Photographs made before the fire (plate 87A) show that some building fronts were thrown out on O'Farrell Street in this vicinity. Many of the buildings hereabouts were mediocre structures at best, but injuries were too generally distributed to be ascribed wholly to structural weakness. The damage was not of great magnitude and did not indicate intensity of Grade B, so far as could be made out from the ruins after the fire.

Near the City Hall there was a small locality conspicuous for the damage produced. The City Hall itself made a picturesque ruin (plates 82 and 83A), as all the world knows, but the character of the construction was probably a large factor in its destruction. Nevertheless ugly cracks in other buildings near by indicated intensity somewhat higher than was common in the valley district as a whole.

Just south of Jefferson Square some weak buildings quite collapsed, and foundation walls were generally cracked and crusht. Wooden underpinning showed a tendency to lurch and throw buildings slightly out of the vertical. Similar effects prevailed along Folsom and Treat Streets for two or three blocks south of Eighteenth Street.

PLATE 82

City Hall, San Francisco.

A. A near view of the wreck at the City Hall, San Francisco.

B. Cattle killed by falling masonry at time of earthquake, San Francisco.

The blocks between the old tide-marsh area, extending east from near the Post-office, and the former course of Mission Creek, give evidence in the form of cracked foundation walls, broken concrete cellar floors, etc., of intensity values high in Grade C. The fire did much to destroy evidence here, as it was a district of wooden dwellings.

From near the corner of Third and King, to the corner of Folsom and Steuart Streets, there is a narrow fringe of land constituting the water-front around Rincon Point. The land is partly natural and partly made. Few structures are found on it which are not built on piling, whether they be warehouses on the docks or good modern buildings. Some parts of the area are devoid of buildings. No evidence was disclosed in this tract indicating intensity higher than Grade C. Significant evidence was scarce. Cracked brick walls here and there served to fix the degree of intensity.

Onward to the north and to the west from the corner of Steuart and Folsom Streets, extends a narrow sinuous area around Telegraph Hill to the vicinity of Black Point, which is designated upon the map as affected by an intensity of Grade C. Such effects as badly cracked brick walls, some of which fell, the fall of cornices and gables, etc., are said to have been developed here. Such evidence as could be made out amid the fire ruins tends to confirm this. This region divides the water-front area of made land, where high intensity was developed, from sandstone hills, where a lesser shock was experienced. It will be discust further in connection with phenomena of special significance.

A low-lying crescent-shaped area of alluvium and sand, with a little made land near the shore, extends westward from Black Point to Fort Point. South, east, and west the hills rise steeply. Formerly a tide-marsh completely separated the alluvial flats from the sandbar at the shore. Part of this, near its mouth, has been filled. Buildings are scantily distributed all over the area. Evidence in the form of structural damage is not, therefore, met frequently. The filled land of the tide-marsh is devoid of structures. There are several little localities in this district marked by damage denoting intensity of Grade B. These will be mentioned later. For the most part, frame buildings occasionally tilted a little out of the vertical, and cracked and crusht foundation walls are typical of the destructive effects found here.

Leading down into this area from near the corner of Polk Street and Pacific Avenue is a minor valley, once deeply trenched, but now modified by alluvial and artificial filling. Along its course most chimneys were thrown and foundation walls were cracked and crusht generally. Two little places, where intensity of Grade B was developed, are situated in the trough. They are discust below.

A group of small areas, 4 in number, together with a small spur of Mission Valley, situated along a line extending northwest from about the junction of Sixteenth and Dolores Streets, is designated upon the map as characterized by intensity of Grade C. It chances that the northwest extremity of this line coincides with the location of an old fault-zone, mentioned above as partly determining the southwestern limits of the serpentine.

In one of these localities, practically bounded by Maple, Spruce, Washington, and California Streets, brick walls and foundations were cracked conspicuously. A building at the corner of Maple and Washington Streets had a balcony supported by pillars above its front entrance. This was thrown down, and the walls were cracked rather badly. It was probably a structure ill adapted to resist earthquake shock. Still it stands directly upon a bare ledge of serpentine, and upon similar rock in the Potrero, an equal distance from the fault, intensity of only Grade E was developed.

At the corner of Maple and California Streets, the Hahnemann Hospital, a new brick building, sustained severe damage, particularly the east wing. If neighboring structures showed any destructive effects comparable with this, intensity of Grade B would be indicated. But they do not. Some cause peculiar to the building itself is responsible for the exaggeration of the intensity. Probably the newness of the masonry was a contributory factor. The surface material here is sand, but it can not be very thick.

Along the same line, near the corner of Waller and Portola Streets, is a little locality of sharp intensity, quite within the lower range of Grade B. It occupies about a block. In the adjoining blocks chimneys fell generally, houses were disturbed slightly on their foundations, and foundation walls were cracked. Here a thin layer of sand occupies the bottom and lower slopes of a sharp little valley. There are low serpentine hills just to the east, with higher chert hills to the west.

In the vicinity of the corner of Van Ness Avenue and Clay Street, there is a low place, or saddle, in the crest of the sandstone ridge where, without apparent lithological cause, there were manifestations of some violence. Some apparently good buildings displayed conspicuous cracks. It is believed that this damage may be in part ascribed to explosions of dynamite used in checking the fire, but in many cases the cracks do not appear to be due to this cause. There is doubt as to the meaning of the evidence here.

In the western part of the city proper, the Richmond district, the Sunset district, and Golden Gate Park, there are several places where chimneys were quite generally destroyed and houses were shifted slightly on their foundations. Loose sand covers the rock to an unknown depth, but this mantle is probably not very thick.

Lake Street, in the vicinity of Fifth, Sixth, and Seventh Avenues, is one of these localities, where, for instance, the Maria Kip Orphanage exhibited conspicuous cracks in its brick walls, as well as fallen gables. In the Home for the Aged, not far away, cracks in the brick walls were numerous. Dwellings of wooden frame construction were less seriously damaged; but even these were much more noticeably affected than others at a little distance. The buildings of these charitable institutions were probably not very well constructed.

A smaller area, on Eleventh Avenue between California and Clement Streets, shows one frame dwelling quite ruined by collapse. (See plate 88A.) This was due to the giving way of a high-posted wooden underpinning. Houses near by are comparatively little affected. It is suggested that this locality is a place filled by grading.

Along First Avenue, between Point Lobos Avenue and A Street, a considerable length of the west wall of the Odd Fellows Cemetery was thrown over to the east. This was a concrete wall 5 or 6 feet high, with a thickness at the base of from 1 to 1.5 feet. It was reënforced near the top by a 2-inch gas pipe running the length of the wall. Houses on the west side of the street were slightly shifted on their basements.

On Third Avenue, between Point Lobos Avenue and Clement Street, the underpinning of houses was disturbed.

The French Hospital buildings, which occupy the entire block bounded by Point Lobos Avenue, Fifth Avenue, A Street, and Sixth Avenue, showed ugly, X-shaped cracks in the brick walls, especially in the central towers. Some brick work fell from the gables, and the chimney stack was broken.

In this part of the city buildings are isolated or in small clusters, with unbuilt districts of blown sand intervening. Consequently evidence was scarce and unsatisfactory.

The Park Emergency Hospital, near the southeast corner of Golden Gate Park, had its walls badly cracked and its gable thrown out. It is a small, 1-story, sandstone building, with a wooden frame. Its site was loose sand of unknown depth, probably extensively graded. Evidently it was not an excellently built structure. The restaurant at the children's playground in the Park was wrecked. (Plate 86.)

The Museum in the Park, not far from the corner of Eleventh Avenue and Fulton Street, was a wooden framed building, with brick and plaster walls. These were cracked very badly, and considerable portions fell. Near by considerable brick and stone fell from the cornice of the music stand. Ugly cracks traversed the hemispherical arch, constructed of sandstone blocks, which served as a sound reflector. The building was made of sandstone blocks, backed with brick. In some of the columns, several of the blocks are moved

PLATE 84

Observatory, Strawberry Hill, Golden Gate Park, San Francisco. W. E. Worden, Photo.

Observatory, Strawberry Hill, Golden Gate Park, San Francisco. W. E. Worden, Photo.

PLATE 86

Restaurant at Children's Playground, Golden Gate Park, San Francisco. W. E. Worden, Photo.

A. O'Farrell Street, San Francisco, after earthquake and before fire.

B. Geary Street, between Filmore and Steiner Streets, San Francisco. Buildings of mediocre construction on sand and alluvium of no great depth. A. C. L.

out of place. Two or three smaller buildings in the immediate neighborhood were also notably damaged. Intensity equivalent to high values of Grade C was certainly developed hereabouts. In some cases it undoubtedly reached low values of Grade B. Yet the glass walls and roof of the conservatory, and of the aviary close by, were not appreciably damaged. This discrepancy shows clearly that some purely local factor determined the amount of damage.

Buildings on the beach sands near the Cliff House, close to the sandstone cliffs of Point Lobos, were strongly shaken. A small 1-story brick pumping station had its walls badly cracked and portions thrown down; its chimney stack also was broken. Weak underpinning in some neighboring frame buildings yielded perceptibly. Here also an abrupt transition is noticed from intensity of Grade C on the sands to Grade D on the sandstone cliffs.

Near Lakeview, fairly well built frame buildings on dune sand of unknown thickness were caused to lurch and shift their positions.

Ocean Avenue, between Ingleside and the sea, tho almost devoid of structures, shows by the unearthing, bending, and even breaking of drainage and water pipes, and by fissures in the road and asphalt paving, a change of intensity from Grade C to Grade B.

LOCALITIES OF LESSER IMPORTANCE AFFECTED BY INTENSITY OF GRADE B.

In the neighborhood of the crossing of Steiner and Sutter Streets, there is an irregularly bounded district a little larger than a city block in which several buildings not conspicuously weak were totally destroyed. St. Dominic's Church, at the corner of Steiner and Bush Streets, was a complete ruin, as the illustration (plate 92A) shows. Its steeple towers were ruined, its roof fell in, and all its walls were so badly cracked that it became a menace to the neighborhood. If the shock had occurred during the hours of religious service, few would have escaped from the building alive. Probably it was not a building of the most excellent construction; but, on the other hand, it did not appear to be built flimsily. It certainly suffered a most violent shaking. Near by small frame dwellings were pitched from their underpinning.

On Geary Street, just above Fillmore Street, two wooden-framed brick buildings standing side by side — the Albert Pike Memorial Temple (Masonic) and a Jewish Synagogue — were utterly wrecked, as the illustration shows. (Plate 87B.) The Girls' High School, near by on O'Farrell Street, at Scott Street, poorly and flimsily built, was badly damaged. Its walls were much cracked and portions of the gable walls were thrown down.

This district of Grade B intensity is on the floor of Upper Hayes Valley and is surrounded by a relatively broad area in which Grade C effects prevail. It lies near the base of the hills which hem in the valley on the east. The surface strata are sand and alluvium extending to no great depth, unless the slopes of the bedrock hills change suddenly where they pass under the mantle of loose materials. No explanation can be offered for the occurrence of this limited area of high intensity (Grade B) unless it be that the district has been converted into "made" ground by extensive grading in the preparation of the surface for building sites and streets.

At the corner of Vallejo Street and Van Ness Avenue, fissures were formed in the asphalt paving, sidewalk pavements were thrust over the curbing, and water-mains and sewers were broken. Buildings were thrown out of the vertical, and foundations and lower story walls were shifted and crusht. The walls about the foundation of one brick building were actually deformed into undulations with much consequent cracking. This building was so badly damaged that it had to be taken down. Surrounding this corner is a small ovoid district, about 2 blocks in extent, in which the intensity was clearly of Grade B. This was once a sharp ravine and had been filled to a depth of 40 feet in order to provide a

suitable grade for streets and buildings. The filling was shaken together and moved slightly downhill.

On Lombard, between Gough and Octavia Streets, is a little area, less than a block in extent, in which the destructive effects were of Grade B. No particularly notable effects were produced. It is a district of made land, formerly the site of a little lagoon in the sands, known as Washerwoman's Lagoon. A portion of Union Street, between Pierce and Steiner Streets, not more than a quarter of a block in length, where a filling had been made to equalize the street grade, was shaken down into the adjacent building lot on the north. The north sidewalk was shifted about 10 feet to the north, and deprest about 10 feet below its original level. The south sidewalk was deprest a few inches and shifted to the north from 2 to 3 feet. The paving and the cable conduit suffered more severe damage than at any other point in the city. The photograph (plate 88B) conveys a graphic conception of the very great violence which occurred here. The phenomena have no general significance, however, despite their striking character, being merely a sliding of unconsolidated material not supported on the sides. But that such places are dangerous building sites, especially in regions subject to seismic disturbances, is unequivocally demonstrated.

Along the north shore water-front, between Fillmore and Steiner Streets, from Bay Street to the water's edge, was a plot of made ground occupied by a gas-producing plant. Here brick walls were cracked and partly thrown down; part of the wooden framework was wrenched out of position, and the chimney stack was broken. One of the large gas-containers was badly wrecked, but whether its destruction was caused directly or in some secondary way, as by rapid leakage, is not known. The intensity was clearly Grade B.

Along Lyon, Baker, and Broderick Streets, north of North Point Street, is a small locality 2 blocks wide and 4 blocks long, where the Baker Street sewer was broken and frail frame buildings were thrown out of the vertical. This district was partly made land, but the greater part was on the point of a sand-pit. Unquestionably extensive grading had been done to prepare the ground for building.

In Golden Gate Park, near the Museum, the granite railing of a stone-arch bridge was shattered by the shock. This was a low balustrade, with many turned granite posts set closely together, supporting a flat, massive granite top-rail. Such damage as it sustained appears to indicate an intensity of Grade B. The bridge was built on loose sand of no great thickness.

On Fulton Street, between Twelfth and Thirteenth Avenues, there was much slumping of the street-filling down into the Park adjacent; and exactly the same sort of damage occurred on H Street, between Ninth and Fourteenth Avenues. Altho, under the definitions, the damage produced in these localities denotes intensity of Grade B, it is believed that the energy of the shock was not greater than elsewhere in their immediate neighborhoods. They were especially susceptible to damage from earthquake shock, being practically loose earth embankments.

Strawberry Hill, in Golden Gate Park, is a chert knob rising abruptly in the sand wastes. Its summit had been leveled, but it is not known whether this was done by cutting off the top and filling out the upper slopes, or by filling alone. The altitude given for the present hill is the same as that given in the earliest accurate surveys. Much artificial stone work, and a circular concrete observatory building 2 stories high, had been erected upon the leveled hilltop. This building was of weak design, having a row of columns, with windows between, which rested upon a foundation wall 3 feet high and supported a heavy second-story balcony. The construction itself was probably good, but the observatory was utterly ruined by the shock. (Plates 84 and 85.) The entire lower story was sheared out of position, and part of the balcony fell. The cement floor showed numerous cracks arranged in a roughly concentric way.

The whole periphery of the hilltop was broken into a series of concentric blocks or steps, and the outer ones moved down the hill from 2 to 3 feet. The artificial stone work was badly cracked and dislodged. These phenomena indicated that the material used in grading the upper slopes had settled somewhat, with consequent rupture of the surface and wrecking of the building. No other explanation can be urged for such striking damage on this hill, in view of the small damage produced on other rock summits in the city.

All the driveways in the western part of Golden Gate Park showed scattered narrow fissures. There were but few structures here, and they did not show significant damage. These were low, strong, frame buildings. It is a district which was extensively graded in the work of landscape gardening, and is underlain by a deep sand deposit. It appears to have suffered a shock of intensity of the middle range of Grade B.

PHENOMENA OF ESPECIAL INTEREST.

About the Ferry Building, at the foot of Market Street, is a district of "made" land, shown on map No. 17, in which high intensity was manifested. Here buildings of all sorts were crowded close together. Wooden buildings, 1 story to 3 stories high, with brick or stone work fronts, were interspersed among ordinary brick buildings from 2 to 6 or 8 stories in height. Mingled with these was a considerable number of modern, class A, office buildings. Here the fire burned fiercely and caused great havoc, heaping the streets and the cellars of buildings with fallen brick and stone and twisted beams and girders. For weeks after the conflagration many of the streets were completely hidden under the débris. So much of the damage due directly to the shock was thereby concealed or obliterated, that no adequate knowledge of the direct effects of the earthquake could be obtained in this part of the city; tho eye-witnesses tell of cornices and gables which fell, and of walls and roofs which collapsed at the time of the shock. After the fire had past, standing walls revealed ugly, sinuous cracks, in rudely parallel systems, which were not due to fire nor to dynamite. Masonry blocks in the walls of excellent modern buildings were broken as by a blow. Rivets were sheared off in parts of the framework of steel structures, and tension rods in such frames were badly stretched. Tubular cast-iron columns, supporting floor girders, were broken off near their bases in cellars where they rested upon piling. The concrete casing of piles was frequently broken. Wherever the intensity was high, the tendency to crack or crush near the base, as tho a sharp blow had been struck there, was notably conspicuous. In spots the streets sank bodily, certainly as much as 2 feet, probably more. Accompanying this depression, concrete basement floors were broken and arched, as if to compensate for it. The surface of the ground was deformed into waves and small open fissures were formed, especially close to the wharves. Buildings on the water side, along East Street, generally slumped seaward, in some cases as much as 2 feet. The damage was greatest close to the water's edge, growing less as the solid land was approached, gradually at first, then more rapidly. These phenomena seem to suggest that the materials used in filling were shaken together so as to occupy less space with the accompanying development of waves, fissures, and structural damage The more recent the filling, the more it would be compacted; hence the greater prevalence and magnitude of destructive effects near the water's edge.

As well as could be made out from the inadequate evidence left by the fire, the district which suffered intensity of Grade B is limited on the landward side by a line drawn from Filbert Street to Market Street, between Battery and Front Streets; thence between First and Fremont Streets to a little south of Folsom Street, where the line turns and runs eastward to the wharves. Flanking this district on the landward side is a narrow, sinuous area limited by a line drawn from Filbert Street to Green Street, just east of Sansome Street; thence between Sansome and Montgomery Streets to Market Street; thence to the corner of Mission and First Streets; thence between First and Fremont Streets

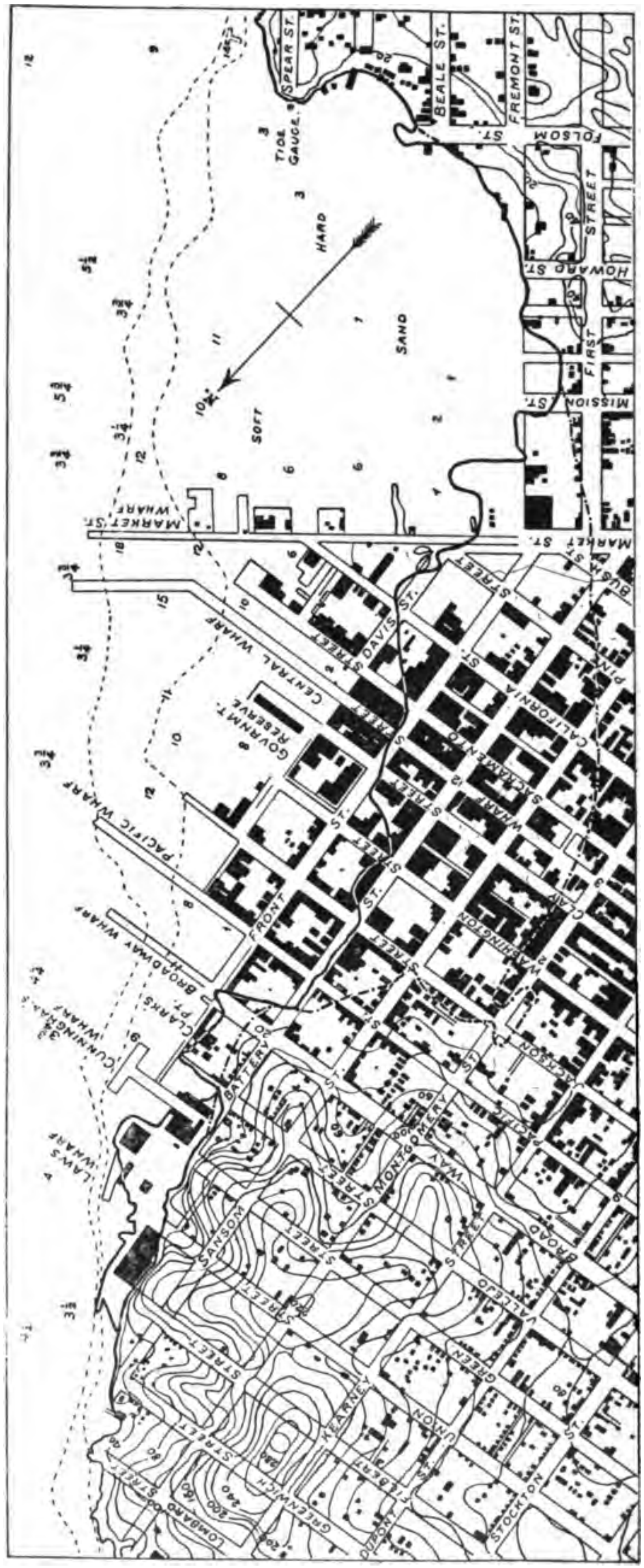


FIG. 51. — Map showing original high-water line of Eddy survey (dot and bar) and mean low-water line or "zero contour" (full line) for district about foot of Market Street in 1853. From Chart of Coast and Geodetic Survey.

to a point south of Folsom Street; thence easterly nearly to the wharves. Between Washington and Sacramento Streets, this boundary is barely east of Montgomery Street. Immediately west of these districts, low intensity prevailed.

It is of interest to inquire whether all or only a portion of this district in which high intensity was developed is "made" land. In the map (fig. 51) is reproduced a portion of the U. S. C. & G. S. chart, "City of San Francisco and its Vicinity," published in 1853 from surveys made in 1851–1852. On it the dot-and-bar line represents the course of the "original high-water line according to plot of Wm. M. Eddy's survey dated 1852." The "zero contour" which determines the configuration of the shore, except where wharves put out, is shown by a continuous line; it is not expressly defined, but it is believed to represent mean low-water, as the soundings are measured from this level. It is needless to point out that this contour is drawn farther seaward than the original high-water line. The portion thus delimited has an area of not less than 20 city blocks, partly or wholly occupied by buildings. Quite outside the "zero contour," as shown on this map, are 8 complete blocks and portions of others — an area of not less than 10 city blocks, partly or wholly built upon. If, then, confidence may be placed in the location of the original high-water line of the Eddy survey of 1852, there were already in San Francisco 30 blocks of "made" land, occupied wholly or in part by buildings before the end of 1853, less than 4 years after the sudden rush to California which followed the discovery of gold in 1849. The revised chart of 1857 shows that very little additional land was made in this district in the succeeding four years.

Without conflicting evidence from other surveys, and no such evidence has been found, the high-water line established by the Eddy survey can not be discredited. Still it is proper to state that these facts raise some doubts as to the accuracy of its delineation, and that the evidence developed by the earthquake does not tend to dispel these doubts. The gradation in the effects produced by the shock, from great magnitude at the water-front to small at the former land margin, would suggest that at least the marginal district where only Grade C intensity was developed, tho outside the location of the original high-water line, might not be made land, altho it has undoubtedly been somewhat elevated by grading. Very little stress can be laid on this suggestion, however, for these districts suffered very severely in the earthquake shock of 1868; but the materials used in filling were then, of course, shaken together, and in addition, the slow settling together from year to year has undoubtedly compacted the earlier made land much more than that recently "made." Besides, the exhibition of damage depends upon the character of the structures in a given locality, as well as upon the ground, and it is to be noted that the buildings along Kearney, Montgomery, and Sansome Streets comprized a larger percentage of excellent structures than the streets nearer the wharves. The problem is thus complex, and very likely unsolvable; but there remains the haunting suggestion that the "original high-water line" does not constitute the landward boundary of the "made" land, properly speaking. At any rate, it is very clear that that which was known to be "made" land suffered much more severely than that which was known to be natural alluvium.

It is important to recognize that, despite the great intensity manifested near the water-front, first-class modern buildings, such as the Ferry Building, built upon deep piling or grillage foundations, were not imperiled by injuries to their walls or framework. Some rivets were sheared off; some tension rods were stretched; an occasional girder was dislodged, and cracks were formed here and there in the brick and stone walls. Large financial loss was unquestionably occasioned, but buildings of this type were not in serious danger of collapse nor of being toppled over, either during or after the shock. Nevertheless conservative engineers recognize that even these structures were weakened. They recognize, too, that future shocks may exert greater energy, and they are trying to devise buildings better able to resist the peculiar stresses of earthquake shocks. The

general public should share their interest, and uphold and enforce the provisions they deem it wise to make against future disasters.

A good indication of the value of deep piling as a foundation structure was furnished by the conduits of the cable-car system on lower Market Street. On account of the constant tendency of the whole district to subside from year to year, as the filling material became more closely compacted, these conduits were constructed upon piling to secure permanence of grade. On both sides of them the street sank in places as much as 2 feet, and the pavement was broken, fissured, and thrown into waves. These tracks did not escape entirely, but for several days, before street repairs were made, they constituted a narrow raised path along the center of the street.

Altho in this part of the city the fire did much to conceal the earthquake damage, a few little spots, especially along the water-front, where water was available, escaped its devastation. A building on Spear Street near Folsom, occupied by the National Bolt Works, illustrates what must have occurred in the case of many small brick structures. Its side wall was thrown down and the entire structure lurched out of plumb. To be sure, this building was heavily loaded on its second floor; still it was not so badly damaged as many partly standing walls in near-by districts swept by fire. The earthquake cracks, being sinuous, and recurring with a rude parallelism, were easy to distinguish from cracks opened by heat, or by the stresses induced by the wrenching away of falling walls or by dynamite. Buildings erected upon good foundations withstood the ordeal well, even when the streets around them were deprest and fissured. The Appraisers' Building furnishes a good illustration of this; it is substantially built of brick upon a piling foundation, at the corner of Washington and Sansome Streets, and still stands without significant damage. The levels of its foundation walls were not disturbed. (See fig. 53.)

High intensity was developed thruout a small elongate district having a width of about two blocks, which extends from near the corner of Eighth and Mission Streets to the vicinity of Fourth and Brannan Streets; from this point the boundaries are irregular and very sinuous, leading to the water-front at about the crossings of Third Street with Berry and Channel Streets. A glance at the geological map, No. 17, shows that the regularly bounded portion of this district corresponds very closely with the area of a former tide-marsh, drained and flooded by one or two small tidal streams. The former shore line of Mission Bay was just north of Brannan Street, between Fourth and Fifth Streets, so that the irregular seaward portion of the district lies outside the old shore.

This is one of two localities in the city, the other being a "made" land tract along the former course of Mission Creek, in which destructive effects of great magnitude were conspicuously developed. Only in very close proximity to the fault was greater violence manifested. For blocks the land surface, paved streets, and building plots alike, were thrown into wave forms, trending east and west about parallel to the length of the area. The amplitude and wave-length of these earth billows, and the distances to which they extend, are indefinite and irregular. The fissuring and slumping, and the buckling of block and asphalt pavements into little anticlines and synclines (arches and hollows), accompanied by small open cracks in the earth, characterize the land surface. This slumping movement or flow took place in the direction of the length of the area, and its amount was greatest near the center, or channel, where the street lines were shifted eastward out of their former straight courses, by amounts varying from 3 to 6 feet. A satisfactory photograph of this phenomenon was not obtainable, owing to the quick convergence of parallel lines in perspective, but to the observer in the field it was a very striking result of the shock.

The greater part of the district was occupied by wooden dwellings and shops, with a small percentage of mediocre brick buildings and a few of substantial construction. The fire swept the area clear. Not even heaps of débris remained to cover the ground, most

A. Frame building on west side of Eleventh Avenue, just south of California Street, San Francisco. A weak structure, built on sand. H. O. W.

B. Slip of a fill on Union Street, just west of Steiner Street, San Francisco. H. O. W.

C. Russ Street, between Folsom and Howard Streets, San Francisco. Paving blocks forced up into sharp arches and dislodged by compression. H. O. W.

D. Moss Street, between Folsom and Howard Streets, San Francisco. Paving blocks archt by compression along sinuous crest, curbing thrown into an inverted V. H. O. W.

A. Columbia Street, just south of Folsom Street, San Francisco. Slumping, depression, and furrowing of block pavement. H. O. W.

B. Bryant Street, near Fourth Street, San Francisco. Flexure of heavily ballasted car tracks in block pavement; an effect of sharp compression. H. O. W.

C. Sixth Street, near Howard. Once occupied by marsh. Street dropt nearly 3 feet. Sidewalk held up by piling foundation of a building. H. O. W.

D. Looking along Dore Street, from Bryant toward Brannan. Undulating and fractured condition of pavement due to earthquake. Houses thrown off their underpinning and pitched out of the vertical. H. O. W.

A. Looking along Dore Street from Brannan toward Bryant. Larger undulations near Brannan. Dore Street is on site of an arm of Mission Creek. H. O. W.

B. Dore Street, near Brannan. Vertical difference between crest and trough of undulations, 5 feet. H. O. W.

C. Eighteenth Street, just east of Shotwell. Fissuring and depression of pavement. H. O. W.

D. Southwest corner Portola and Waller Streets. Buildings have shifted down hill slightly, upper parts more than lower. H. O. W.

A. Ninth Street, between Bryant and Brannan. Undulation and fissuring of pavement and sidewalks. Houses over trough have been dropt from their underpinning. G. K. G.

B. Ninth Street, between Bryant and Brannan. Westward lurching of land toward former creek channel where Dore Street now is. G. K. G.

of the destructive effects being obliterated, along with the structures in which they were developed. Enough remained, however. Foundation walls and sidewalk pavements were broken and flexed; sharp little anticlines were produced in the street by the arching of block paving, as on Russ Street between Folsom and Howard Streets (plate 88c); granite curbing was broken and thrust up into an inverted V, as on Moss Street, between Folsom and Howard Streets (plate 88D); there were fissuring and slumping in the block pavement, as along Columbia Street between Folsom and Harrison Streets (plate 89A), and sharp flexures of the paved streets and car tracks, as on Sixth Street just south of Howard Street. These effects point simply and clearly to the great magnitude of the intensity thruout the greater part of this old swampy district.

Attention has already been directed to the slumping or flow movement to the east along the long axis of the area.

The heavily ballasted car-tracks on Bryant Street, at the crossing with Fourth Street, were sharply flexed laterally, tho bounded by block paving. (Plate 89B.) This was at the eastern end of the district where the marsh formerly bent to the south around the flanks of Rincon Hill, a mass of firm sandstone rising from the floor of Mission Valley. No similar sharp flexures were encountered along east-west streets in the western or central portion of the district, tho lateral displacement and flat, sinuous curvings of the street lines were common enough; notably on Harrison Street between Fifth and Sixth Streets, and on Folsom Street between Fourth and Seventh Streets. Both these streets cut across the direction of the flow movement at a small angle. These phenomena are easy to understand if, as seems certain, Rincon Hill served as a solid buttress against which the flow to the east was arrested, causing sharp crumpling of the surface near the buttress, with less disturbance farther away. This was combined with a slight tendency to flow southward in the southeastern part of the district.

The shaking caused the materials used in filling to settle together and occupy less space, so that the surface over the whole district was lowered by amounts varying from a few inches to 3 feet or more. This is clearly seen in the change of street levels along the margin of the solid ground, where the car rails are bent downward in little monoclines. Occasionally a structure with a relatively good foundation remains at its former level, with the whole neighborhood deprest about it. Such a case is exemplified on Sixth Street, a little south of Howard Street, near the margin of the area. (Plate 89c.) The flow movement is thought to be due simply to the action of gravity, the loose, water-soaked material being compacted into less volume by the shaking. Besides this sinking of the district, and its flow movement, mention has been made of the deformation of its surface into irregular waves, trending approximately east and west parallel with the length of the district. Along the streets running approximately north and south, at right angles to the elongation of the area, car rails were bent abruptly to the side, or raised in arches, and sharp anticlines were formed in the block pavements. Large square concrete slabs, used for sidewalk paving, were thrust one over the other; and in one or two cases a slab entirely covered an adjoining one. These phenomena indicate shortening by compression in the north-south direction. On the other hand, however, a stretching of the surface is shown by fissures in the paving; by places where wedge-like blocks were deprest below the general level; and by the rails of car tracks which were pulled apart in amounts varying from 8 to 12 inches. Owing to the relatively great and very variable structural strength of paved streets and heavily ballasted car tracks, these phenomena are not developed regularly nor frequently enough to afford a satisfactory test of the hypothesis that they are directly associated with the wave forms into which the surface of this district was thrown. Besides, owing perhaps to the varying rigidity of the materials which make up the surface of the streets and building plots, the wave forms themselves, tho generally prevalent, are not persistent in their extension. The compression and disten-

sion effects, however, are believed to be due to the same cause as that which generated the wave forms; for there is no evidence of any true shortening, or lengthening, of the north-south dimension of this district, nor is there any probability of this having occurred.

In addition, then, to the flow movement and the settling together of the loose materials causing depression, there was some sort of rhythmic movement in this loose earth which produced wave forms in the surface, with places of compression and places of stretching. It probably was this movement which was most effective in producing structural damage. It is not believed that these surface waves were traveling waves "frozen" as the shock subsided. If they had been of that character, the ground surface should be more broken than it appeared to be; for in relatively rigid materials such waves must develop open fissures along the crests, which would close with crushing in the troughs. It must be noted, without any attempt at explanation, that the destructive effects of great magnitude which have been described above, are practically confined to the "made" land which occupies the old marsh site.

Southeast of Brannan Street, where formerly lay Mission Bay, such effects are of less magnitude, in general; are less regular in their occurrence and are, on the whole, less prevalent. The complete devastation caused by the fire in this neighborhood leaves little to indicate the actual damage to the buildings wrought by the earthquake. Certain hotels or apartment houses are known to have collapsed, and many fatalities must have occurred. Probably a few dwellings were thrown down. A fairly large percentage of the buildings, one must believe, were rendered dangerous for occupation, even tho not completely thrown down.

The new United States Post-office building (plate 94B), at the corner of Seventh and Mission Streets, was just on the margin of the district. It is a steel and granite structure, resting upon a foundation of piling driven to a considerable depth, but not as far as some had considered advisable. At its southwest corner, the streets are deformed into great waves, some with an amplitude of at least 3 feet, causing fissures and sharp compressional arches in the pavement and sidewalks. Some of the granite flanking structures, which did not rest upon the pile foundation of the building, shared this undulatory movement. In consequence, the building appears badly damaged to the casual observer. It is quite true that the structure was terribly shaken and greatly damaged — such injuries as the destruction of mosaics in the arches of the corridor helped to increase the loss — but the structure was not in peril of collapse, tho one of the low walls had to be supported by timbers. For the most part, the building survived the ordeal, and is in a safe condition for use.

As stated briefly above, a similar district of high intensity occurs in an area of made land along the lower portion of the former course of Mission Creek. This district varies in width from 1 to 2 blocks, extending from near the corner of Ninth and Brannan Streets westward for about 3 blocks, then southwestward for about 2 blocks more; and finally, westward some 4 blocks more to a point on Nineteenth Street just east of Dolores Street.

Mission Creek was formerly a sinuous tidal stream, with narrow fringes of salt marsh about its banks. Near its mouth the stream wound around a rocky point where the serpentine hills of the Potrero rose abruptly from its southern bank. Here, along its margin, is found the most sudden transition from high to low intensity that is anywhere encountered in the city. Along Dore Street, a narrow alley running from Bryant Street to Brannan Street, between Ninth and Tenth Streets, the street pavement was broken into a series of waves. The photographs, plate 89D, looking along Dore Street from Bryant toward Brannan Street; plate 90A, looking from Brannan Street in the reverse direction; and plate 90B, showing in detail the trough of one of these waves, with the fissuring of the pavement near the farther crest, indicate more clearly than words the great intensity manifested here. Less than 2 blocks south on the hill slopes, more than

A. St. Dominic's Church, Bush and Steiner Streets. Brick and masonry structure upon sand and alluvium of no great depth. A. C. L.

B. Looking south on Howard Street from near Seventeenth Street. Compressional flexure of car rails. G. K. G.

50 per cent of the chimneys were left standing, and no serious structural damage was noted. No comment seems needed to establish clearly the fact that the change in the character of the ground, this being the only variable factor, is in some way the cause of the change in the degree of intensity.

On Ninth Street, east of Dore Street, between Bryant and Brannan Streets, the block pavement was badly damaged by fissuring, slumping, and the formation of surface waves. Frame dwellings were thrown from their underpinning, and a few collapsed. Plate 91A shows a wave trough near Bryant Street, with the resulting disturbance of the pavement. The dwellings immediately in the trough have dropt from their foundation posts. In plate 91B, looking along Ninth Street from near Brannan Street, is shown the depression and fissuring of the street and its slumping or flow westward toward the former channel of a short branch of Mission Creek, which occupied the present location of Dore Street. Streets, curbing, car tracks, etc., are deflected from 6 to 8 feet from their former positions. The frame dwellings were not destroyed, but a careful examination of the picture will show that most of them are badly injured. Many were left in a dangerous condition by the shock.

On Tenth Street, between Bryant and Brannan Streets, less violence was noted and the slumping of flow eastward (toward the channel of the little branch of Mission Creek) is scarcely noticeable.

Again, along the creek bed frcm Folsom Street, between Seventeenth and Eighteenth Streets, to the vicinity of Valencia Street at Eighteenth, great destruction was conspicuously prevalent. Less than a third of the frame dwellings in this tract retained their vertical positions, and a few collapsed completely. Others remained standing only by leaning against each other. The south side of Howard Street, between Seventeenth and Eighteenth Streets, which escaped the fire, furnishes a good illustration of the damage produced here. (See plate 93A.) As in other places, the streets were deprest, fissured, and thrown into waves. (Plate 90C.) Car rails were arched and bent laterally in a violent fashion. (Plate 92B.)

Sewers and water-mains were broken. At Eighteenth and Valencia Streets there was a serious break in the water-pipe. Here, on both sides of the street, the ground sank about 6 feet, causing the roadway to arch in a very noticeable way. (Plate 93B.) Ten-inch car rails were bowed up into arches from 24 to 30 inches in height. The Valencia Street Hotel collapsed so that occupants of the fourth story could step out into the street. Casualties in this district can never be known accurately, owing to the immediate onset of the fire, and the complete devastation it produced.

On land made by filling in, "The Willows," a marshy tract formerly extending up the Eighteenth Street Valley from Mission Lagoon, near the corner of Nineteenth and Guerrero Streets, there was observed a considerable slumping or flow movement of the surface. The photograph (plate 94A) shows the Youth's Directory, a charitable institution for boys, where the street and building were moved northward and slightly eastward, toward the former channel and downstream, fully 6 feet.

Enough evidence has been cited to demonstrate that high intensity prevailed thruout this district. Here, as in the other tract of made land which occupies the site of the old tidal marsh, the materials used for filling were shaken together, and caused a general depression of the surface over the whole district, accompanied by slumping or flow movements. The surface was deformed into waves, with accompanying fissures and sharp compressional arches. Here too, as in the tract previously described, the materials used for filling constitute a relatively thin rigid layer deposited upon the marshy fringes or in the shallow waters of the creek.

The creek (see map No. 17) formerly extended for about 2 blocks eastward from Ninth and Brannan Streets before it reached the old shore line of Mission Bay. This portion

of its course is now occupied in large part by the railway tracks and structures of the Southern Pacific Company; and the exceptionally strong foundation necessarily provided for the railway line probably explains why less damage was found here than one would at first have expected. At any rate, the greatest damage noted was the cracking of brick walls and the falling of cornices.

The space formerly occupied by Mission Bay has been partly filled to provide building sites, and of course the materials used in filling were deposited in water. The district is occupied in part by structures of great strength, such as railway tracks; in part it is devoid of buildings. Thruout the district, evidence was insufficient and inconclusive. Except near the former outlet of Mission Creek, and in the area further north formerly occupied by the tidal marsh, the destruction produced does not denote intensity higher than Grade C. Apparently, therefore, land made by filling up spaces of open water is less dangerous, on the whole, than land made by depositing a thin rigid layer of filling upon a tract of marsh land. This, at least, is the lesson in San Francisco. The reasons for it are not very clear. Space forbids a discussion of theories which can not be adequately tested. It may be noted, however, that much of the material used in filling in areas of water has been broken rock derived from the grading down of neighboring rocky hills.

Near the corner of Waller and Portola Streets, not far north of the head of Market Street, is a locality, less than a block in extent, where houses were shifted slightly on their foundations; their upper stories were moved farther eastward (downhill) than the foundations, as a result of shearing in the framework of the basement or of the first story of the buildings. (Plate 90D.) There also occurred minor bucklings and breaking of the thin asphalt pavement. The intensity, which belongs low in the range of Grade B, diminishes rapidly in all directions, and the district is surrounded by a band where the intensity is Grade C. Here a thin layer of sand reposes upon the slopes of a little upland valley between the low serpentine hills to the east and the high chert hills to the west. The effects are such as would be produced by a shaking downhill of this thin sand layer, with the structures which rest upon it. This seems the best explanation of high intensity in this district. Attention, nevertheless, must be directed to the fact that this, and three other districts shown on the map, No. 19, lie roughly along a straight line which nearly coincides with the western boundary of the serpentine body. At its northwest end, this boundary is known to be determined by a fault of considerable throw, constituting consequently a weak place in the crust of the earth here. It is not known how far southeast the fault extends, and it is not unlikely that it cuts entirely across the peninsula. The recurrence of these little districts of comparatively high intensity suggests that it continues as far south as Market Street, at least, and that such a zone of weakness was especially suited to the production of high intensity by the shock. This hypothesis can not be conclusively tested, but it is interesting and important enough to merit presentation and to receive attention in the event of future earthquakes.

In support of the statement made in the foregoing pages that the intensity increases markedly as one approaches the fault, independently of the character of the ground and other factors, the following evidence is presented:

Forty-eighth Avenue, between K and N Streets, is a district underlain by deep sand where extensive grading operations were undoubtedly necessary to convert an area of sand-dunes into streets and building lots. Here small, substantial frame dwellings were shifted bodily from 1 to 2 feet out of position, and the streets were slightly dislocated. Telegraph poles were thrown down or caused to lean over so much that only the tension of the wires kept them from falling completely, and lamp posts were overthrown. The dwellings suffered little structural damage, owing to their small, substantial character, and to their being built close to the ground; so that when shifted from their underpin-

A. East side of Howard Street, between Seventeenth and Eighteenth Streets. A. C. L.

B. Valencia Street, near Eighteenth. Land in this neighborhood sank about 6 feet, flexing street surface. A. C. L.

A. View along Nineteenth Street, from Guerrero Street. Both ground and buildings moved north about 6 feet toward center of old marsh, with component of movement down the channel. A. C. L.

B. San Francisco Post-office, Mission and Seventh Streets. Near corner of building is on edge of old marsh. Ground over marsh sank and lurched. W. E. Worden, Photo.

ning, they had but a few inches to fall. Still, it is the opinion of the writer that the intensity developed here was little, if any, short of the maximum on the made land in the city, tho the conditions were not such as to permit so great damage.

On Ocean Avenue and X Street, near where the former outlet of Lake Merced flowed, fissures were developed in the street and in the sands on either side, and water was squeezed out so as partly to flood the roadway. Drain pipes were unearthed and bent or twisted.

From the former outlet of Lake Merced, where W Street meets the Grand Ocean Boulevard, or Great Highway, southward along the ocean, low cliffs of soft rock — the Merced sandstones and shales — rise abruptly from the beach. These mount gradually as we go southward, until at Mussel Rock they attain a height of 500 feet. All along this line of cliffs, and for a short undetermined distance inland, the rock masses were cracked, broken, and traversed by narrow fissures. These effects grow more and more numerous and of greater and greater magnitude until, a short distance north of Mussel Rock, the fault is reached. A short distance south of X Street, a small, substantial frame dwelling, built upon a good foundation under the cliffs by the beach, was almost overturned. South of this there were no structures along the beach except the seaward end of the Lake Merced Tunnel, an hydraulic arch which was slightly broken, tho embedded in the rocks of the Merced formation. All along the faces of these cliffs, much material fell or slid down to the beach.

CONCLUSIONS.

This investigation has clearly demonstrated that the amount of damage produced by the earthquake of April 18 in different parts of the city and county of San Francisco depended chiefly upon the geological character of the ground. Where the surface was of solid rock, the shock produced little damage; whereas upon made land great violence was manifested. Other things being equal, there was a decrease of intensity from the southwest toward the northeast, as the distance from the zone of faulting increased. Other conditions, however, exerted a controlling influence. There was, for instance, much greater contrast, in the destructive effects produced, between the summit of Telegraph Hill and the vicinity of the Ferry Building, about a quarter of a mile apart and at practically the same distance from the fault, than there was between the damage produced near the Ferry Building and along the trace of the fault itself. (Consult the intensity map and profiles.) In this part of the zone of destruction, change in distance from the fault clearly did not influence the gradation in intensity, so much as did change in the character of the ground.

ADDENDA.

Subsidence of made land.—The unstable character of the made land on the waterfront of San Francisco has long been known. This instability made itself manifest in a progressive subsidence which, in the course of years, rendered it quite difficult to maintain the grade of the streets. An effort was made by Mr. C. E. Grunsky, when he was city engineer, to determine the rate of this subsidence, and the following extract from his report as city engineer for the year 1902–3 is not without interest in connection with the violent disturbance of the ground caused by the earthquake in the areas of made land:

> Examination has again been made to determine the amount of sinking in those improved portions of the city where subsidence has heretofore been observed. The result of this examination appears from the following table, in which is also given the subsidence which occurred during the preceding year.

Street.	From —	To —	Subsidence in Feet. April, 1901, to April, 1902. Max.	Mean.	April, 1902, to April, 1903. Max.	Mean.
1. Davis	Market . . .	East	.07	.05	.08	
2. Jackson . .	Montgomery	East	.07	.03	.06	
3. Spear	Market . . .	Bryant . .	.10	.06	.05	
4. Mission . . .	First	East	.11	.07	.05	.02
5. Harrison (a)	Fourth . . .	Seventh . .	.17	.15	.22	.19
6. Sixth	Howard . .	Channel . .	.10	.05	.17	.08* .05§

(a) Location of maximum subsidence on Harrison Street between Fourth and Seventh is the same for both years.

* Mean subsidence from Brannan southerly. § Mean subsidence from Brannan to Howard.

1. No appreciable subsidence (Apr. 1902–Apr. 1903) except at Vallejo Street, where maximum occurs.

2. No appreciable subsidence (Apr. 1902–Apr. 1903) except at Drumm and East Streets, where maximum occurs.

3. No appreciable subsidence (Apr. 1902–Apr. 1903) except at Mission Street, where maximum occurs.

4. Subsidence (Apr. 1902–Apr. 1903) occurs from Main easterly; maximum at East Street.

5. Subsidence (Apr. 1902–Apr. 1903) occurs from a point between Fourth and Fifth Streets, as far west as Sixth Street.

6. Maximum (Apr. 1902–Apr. 1903) at Folsom Street.

Possible premonitory movements (Miss H. C. Lillis). — Mr. McConnell, a jeweler, located on Post Street between Montgomery and Kearney Streets, states that 4 days before the earthquake he found one of his windows broken in nearly 50 pieces tho none of the pieces had fallen out; and supposing that some one had tried to enter his shop, he sent for a detective. Captain Calunden came, and on looking over the premises declared that it was not the work of a burglar but was due to the settling of the building. He found the building out of plumb. This would indicate a settling of the ground before the shock. One of his workmen who lived in the Mission found his cellar door closed so that difficulty was experienced in opening it. This occurred the same day as that on which the glass was broken.

Effect of the shock near the beach (W. D. Valentine). — We were residing on Forty-eighth Avenue, between K and L Streets, within a few hundred feet of the ocean, about 0.5 mile south of the park. In our section the shock was violent. It awakened me instantly, and for a few seconds I was unable to rise, as I was thrown back in the effort. Meanwhile I was carefully watching the movements of an extremely tall and heavy oaken wardrobe which stood almost in the middle of the floor. The top first swung to the west, then to the north, then to the east, and fell directly to the south with such force that it went to pieces. Our heavy upright piano and various heavy articles of furniture were thrown completely over. The sand in our basement raised from 1 foot to 18 inches. A wide and long 3-foot depression was raised level. Our lot, which was 120 feet deep, was shortened at least a foot, which was shown by the folding of the fence. Electric-light poles in the street in front of us, which were in the sand, were thrown down north, east, south, and west. There was a fissure for about a block, between Forty-seventh and Forty-eighth Avenues, about 3 feet wide and 6 or 8 inches deep,

which was of course in the sand. There were also other blow-holes in the sand, which emitted water and sulfurous odors.

Effect of the shock on the gas plant and pipes (E. C. Jones). — The earthquake movement was apparently from north to south, inferred from the fact that bookcases and china closets placed east and west were almost invariably tipt over, or their contents thrown out; while those placed north and south were in most cases undisturbed. Gas-mains in streets running east and west were broken and drawn apart, while those in streets running north and south were crusht together and telescoped, or else raised out of the ground in inverted V's. This rule applied generally, with but few exceptions.

On Jackson Street, between Drumm and Davis Streets, which is made land, the street main was laid on a line of piles which went to hard pan. The piles were not purposely driven to sustain the pipe, but happened to be in the line of the main when it was laid. This pipe broke over the center of each pile, 9 in number, and was not broken in the made ground where it was unsupported.

During the latter part of the first shock, there was a rotating motion which had the effect of twisting gas-holders out of their guide frames.

The foreman of the North Beach Station was looking at the 2,000,000-foot storage holder, and described it as follows:

> On going to the window, I lookt at the storage holder, which was vibrating like an inverted pendulum, and waves of water were coming over the wall of the tank. The relief holder was similarly affected with water and tar coming over the tank wall. The shrubbery in the garden was shaken as tho by a strong wind.

These two holders were heavily framed with latticed girders, and did not leave their guides by the rotating movement of the earthquake.

The storage holder at the Pacific Gas Improvement Company's Works was twisted around 2 feet from the guide rails, while at Martin Station the 1,500,000-foot storage holder was twisted 5 feet on the lower section, 8 feet on the middle section, and 12 feet on the upper section. At this plant the 4,000,000-foot generator was moved bodily 2.5 inches to the south. All connections were of steel, and no joints were broken.

A barn at the North Beach Station, corner of Laguna and Bay Streets, was resting upon wooden uprights about 16 inches high. These uprights were tipt over, and the barn moved the length of the uprights toward the south; that is, after the earthquake it stood 16 inches on the sidewalk.

The buildings at the different plants did not suffer according to their relative strength. Some brick buildings of comparatively poor construction were unharmed. Other buildings of great strength, with heavy footings on good foundations, were shaken to the ground, particularly those running east and west; while buildings of the same or less strength, with foundations not so good, but running in a direction north and south, were but little injured.

Effect on certain street railways (T. Mallally). — There does not seem to have been any actual shortening of the length of the street railways of the United Railroads of San Francisco; but the rails in one location traveled about 3 feet in a northerly direction. This location was in the valley and was marsh land, beginning at a point about 100 yards north of Holy Cross Cemetery, where the rails parted, and ending about 1,000 yards north of Holy Cross, where the rails buckled up in the air. We had to cut out about 3 feet at this point, and add 3 feet where it parted at the other end. Of course there was a decided movement of the rails all along, in a lateral direction, which left the tracks out of alinement, but was not enough to prevent operation of cars.

This condition would indicate that the fill in the marsh land moved in a northerly direction about 3 feet, but that the actual distance along our line has not been appreciably changed.

Deformation of the U. S. Government buildings. — For the purpose of determining the extent of the deformation of the three U. S. Government buildings — the new Post-office, the Appraisers' Building, and the Mint — the Coast and Geodetic Survey, at the request of the Commission, determined on July 12, 1906, the relative levels of the four corners of each of these structures, as indicated in the accompanying notes and figures. The leveling was done by Mr. C. H. Sinclair. The memorandum of Mr. Sinclair's results, which was placed at the disposal of the Commission by the Superintendent of the Coast and Geodetic Survey, is as follows:

New Post-office. — Fig. 52 shows by numbers the positions of the stations occupied; and the points at the corners, the relative levels of which were determined, are indicated by their orientation.

The southwest corner is the lowest and is the only one that settled materially, being about 0.393 foot = 4.72 inches lower. The outer walls have cracks in many places. This is a fairly good showing for a bad foundation.

Sights nearly equal except at II, where backsight is about 100 feet and foresight is about 300 feet. Street so low that readings could not be made any other way. Cars and drays passing all the time. Wind bad. Rod held on circular molding (tower, ½ circle section) which was the lowest projection built into the wall that was common to the four extreme corners.

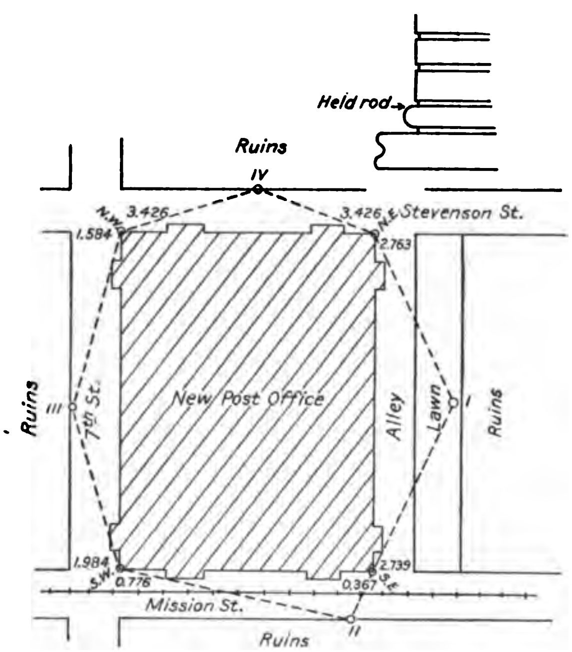


Fig. 52. — Map showing relative levels of four corners of new Post-office, San Francisco.

Level at—	Corner.	Feet.	Difference.
I	NE. SE.	2.763 2.739	0.024
II	SE. SW.	0.367 0.776	0.409
III	SW. NW.	1.984 1.584	0.400
IV	NW. NE.	3.426 3.426	0.000

Appraisers' Building. — Fig. 53 shows by numbers the position of the stations occupied; and the points at the corners are indicated, as before, by their orientation.

The northwest corner is 0.909 foot = 10.908 inches above the southwest corner. The northeast corner is 0.909 foot + 0.054 = 0.963 foot = 11.556 inches above the southwest corner. The southeast corner is 0.080 foot = 0.96 inch above the southwest corner. The rod was held on top of water-table at each of the four corners, and the sights were nearly equal in length. The south side of the building is about 11.23 inches lower than the north side.

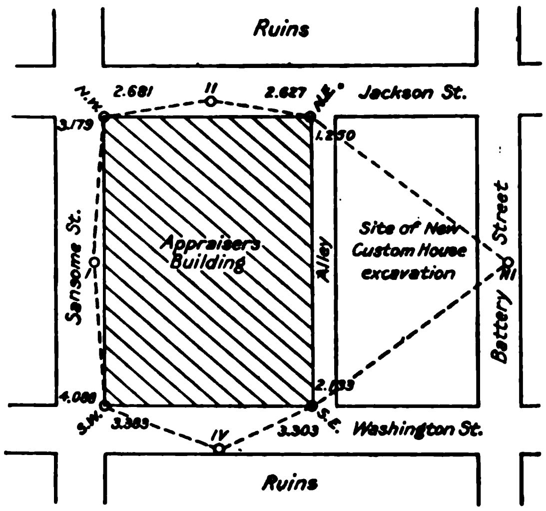


FIG. 53. — Map showing relative levels of four corners of Appraisers' Building, San Francisco.

Level at—	Corner.	Feet.	Difference.
I	SW. NW.	4.088 3.179	−0.909
II	NW. NE.	2.681 2.627	−0.054
III	NE. SE.	1.250 2.133	+0.883
IV	SE. SW.	3.303 3.383	+0.080

Mint. — Fig. 54 shows by number, as in the former cases, the positions of the stations occupied and the points at the corners are indicated by their orientation.

The southwest corner is the lowest, being 0.498 foot = 5.976 inches (mean) below the northwest corner. The walls on the north side are badly scaled by the heat. No serious cracks were noticed in the outside. The rod was held on top of the water-table at each extreme corner of the building. Street cars constantly passing on both Mission and Fifth Streets, also heavy drays. The wind was very troublesome. Sights were nearly equal.

The deformation indicated by the above measurements can not be wholly referred to the earthquake, since it is quite probable that the structures had settled somewhat before that event. It appears, however, to be desirable to put the measurements on record for future reference.

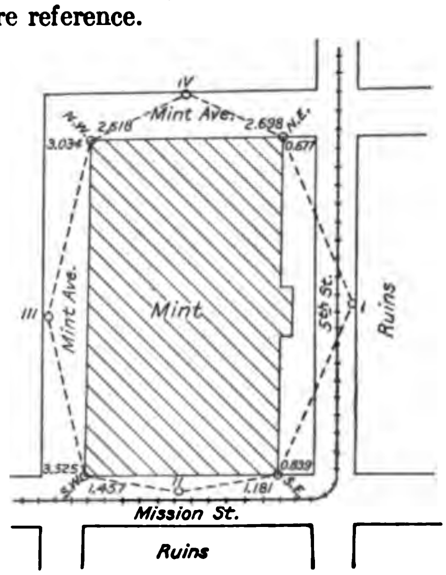


FIG. 54. — Map showing relative levels of four corners of Mint, San Francisco.

Level at —	Corner.	Feet.	Difference.
I	NE. SE.	0.677 0.839	0.162
II	SE. SW.	1.181 1.457	0.276
III	SW. NW	3.525 3.034	0.491
IV	NW. NE.	2.618 2.698	0.080

THE SAN FRANCISCO PENINSULA.

BY RODERIC CRANDALL.

The distribution of intensity in the San Francisco Peninsula, south of the city, was studied by Mr. Roderic Crandall, under the direction of Prof. J. C. Branner. The following is Mr. Crandall's report on that territory:

For a consideration of the detailed effects of the earthquake thru the area of the San Francisco Peninsula, it will be convenient to divide the country into two portions along the San Andreas fault, and to subdivide the area northeast of that line into two parts; namely, the San Mateo district, and the Merced Valley.

THE SAN MATEO DISTRICT.

The towns of San Carlos, Belmont, San Mateo, Burlingame, Millbrae, and San Bruno are included in the San Mateo district. These towns all lie along the railroad between San Jose and San Francisco, and are in almost a straight line; that is, parallel to and at a distance of from 2 to 4 miles from the San Andreas fault. They are all situated about the same geologically, being upon the Santa Clara Valley floor just at the east edge of the foot-hills of the Santa Cruz range.

San Carlos. — The railway station at San Carlos, a low 1-story stone building, was badly damaged, some of the walls being partly thrown down, and the rest of the building cracked. A large frame house near the station was shaken from its cement foundations, and the foundation itself was badly cracked.

Belmont. — Between San Carlos and Belmont, over four-fifths of the houses lost their chimneys, but no buildings were thrown from their foundations. At Belmont a majority of the chimneys fell. Reid's school and other buildings in the neighborhood of Belmont sustained similar damages. Reid's school is one mile nearer the fault-zone than Belmont, among the low foot-hills. Thru the hills west of Belmont no cracks nor big landslides were found, but there were small landslides along the road leading from Belmont to Crystal Springs Lake. A tall stand-pipe on the hill southwest of Belmont was unaffected, but it is a well-built structure, guyed with wire cables, and might sway without falling. Near Homestead, in the foot-hills between Belmont and San Mateo, the brick building of the Crocker Orphanage was completely ruined.

San Mateo. — San Mateo showed the intensity of the earthquake plainly.[1] Almost all brick and cement buildings were damaged and several were completely ruined. (See plates 98A, B, and 99A, B.) Many wooden structures suffered by being thrown from their foundations, while others were shifted without material damage. Nearly every brick chimney in town was shaken down, with consequent damage to the houses.

At San Mateo Point, which is on the shore of San Francisco Bay, east of the town, low frame buildings were uninjured. Tanks 5 feet deep and 4 feet wide, which were half full of water, were almost emptied by the shock, the water spilling to the southwest. The alluvial flats around the point showed some small cracks, and there was a slight sinking of the ground near the bay.

According to the man at the boat-house at San Mateo Point, the waters of the bay were quieted by the shock. Another man, who was in a boat at the time, felt the shock but not very strongly. Several fairly heavy shocks about 6 o'clock that morning were not felt at all by men on the waters of the bay. At a lumber yard, about half a mile west of the point, part of the wharf was broken, lumber piles were overturned, and a chimney fell.

[1] See Robert Anderson's paper on San Mateo and Burlingame in a later part of this report for statistical details.

Burlingame. — Along the line of the electric railway from San Mateo northward, many of the poles were left out of a vertical position, most of them leaning toward the northeast. At the Brewer School, in the foot-hills, about due west of San Mateo, little damage was done. A tall, well-built tank-house remained standing, tho the roof built over it, a slight, flimsy structure, was turned thru an angle of approximately 30°, but remained on top.

Tho there were no large brick buildings, many of the houses in the vicinity of Burlingame were badly wrecked, due to the falling of extra heavy chimneys thru the roofs. Brick walls generally fell, unless low and especially well built.

Millbrae. — At Millbrae there are but few buildings that could be affected by the shock, but the brick power-house of the San Mateo electric line was partly wrecked. The north and south walls fell, while the east and west ones remained standing. The latter stood because they were held by the steel trusses which spanned east and west.

In the vicinity of Millbrae and San Bruno, it was found that several of the small creeks were well filled with débris of various kinds that had been brought down by an unusual flow of water following the shock, and several days after the earthquake the streams were still carrying a small amount of water.

San Bruno. — Near San Bruno, where the county road crosses a small stream, there were numerous cracks in the ground from 3 to 10 inches wide, parallel to the line of the road, which is N. 25° W. The road at this place was built 8 feet above the mud flats, so that these cracks are accounted for by the settling of the fill. There are not many houses in the vicinity of San Bruno Station by which to judge of the intensity, but in the few houses seen the chimneys had all fallen. The race-track buildings at Tanforan, north of San Bruno, were not materially damaged, altho the buildings and bleachers are flimsy wooden structures. Plate 97C illustrates the effect of the shock upon the track of the electric railway on the marsh west of San Bruno.

THE MERCED VALLEY DISTRICT.

The Merced Valley district includes not only the valley proper, but also the area covered by the main body of the Merced sediments, from the San Andreas fault-line, east by Baden to South San Francisco and along the southwest face of the San Bruno Mountain, and by the cemeteries to the Life Saving Station on the coast north of Lake Merced.

Baden. — Baden, at the south end of the Merced Valley, consists of only a few houses, none of which shows marked effects of the earthquake. The track of the electric tramway line, just south of Baden, shows evidence of intense disturbance. (See Plate 97D.) The roadbed which was built up nearly all the way here was cracked parallel to the rails. One crack varied from 2 inches to a foot in width, and extended about 1,000 feet along the filled-in roadbed. For this distance the double tracks were twisted back and forth in a zig-zag fashion, and up and down to some extent. One rail was bent 2 feet horizontally and 10 inches vertically. Not a single rail in this 1,000 feet remained straight or in place, but in no case were the rails detached from the ties. Most of the poles supporting the electric wires were thrown out of line. The ties were shoved back and forth and from side to side, leaving clean, bare places where they had slid about.

The tracks of the Southern Pacific Railway line, which are parallel to the electric road in the vicinity of Baden Station, were slightly disturbed but not so badly that trains could not run over them. The Southern Pacific roadbed is much better ballasted than the electric line, because it is older and has become more firmly packed, which is the reason that it was not disturbed like that of the electric line. This disturbed portion of the electric line continues about 200 feet north of a road by the Baden Station, until a cut is reached where filling up was no longer necessary. The cracks were thus confined to the filled ground.

Just east of the station at Baden, where a creek crosses the county road, there were cracks in the filled soil, and there was also evidence that in this low ground the creek had flooded a distance of 100 feet on both sides of its usual course. At the time of the first visit, about 3 days after the shock, there was more water in the creek than there had been the previous week. At this same place, a steel water-main, supported on trestlework, was wrenched so that it leaked badly.

At Big Frawley Canyon a trestle carrying a 30-inch water-main was demolished. (See plate 100A.)

The electric-car line that runs to South San Francisco turns a right angle at Baden, from northwest to northeast. The rails northwest and those northeast of the turn were both badly bent. On the northeast branch the rails were bent into a U-shape, the base of the U being to the northwest with a side thrust of about 2.5 feet. The rails on the northwest end of the line were bent into a V, with the base of the V pointing northeast, the lateral displacement being about 1.5 feet. These are about 60-lb. rails, and at the V-shaped bend mentioned the rails were broken in three places.

South San Francisco. — 1.5 miles east of Baden, at South San Francisco, the intensity was considerably lower than at the previously mentioned places. Many chimneys fell, but no badly wrecked houses were seen. At this place the corner fell from a new brick building, under process of construction, and some of the other large brick buildings were slightly cracked. The damage at South San Francisco was not large, taken as a whole. (See plate 97B.)

A little more than a mile east of the town, there are several tall brick stacks, none of which fell. Some were entirely uninjured and others slightly cracked, but only one, so far as known, was badly enough damaged to require rebuilding. The brick structures and stacks at the packing house did not suffer materially.

Some of these buildings are almost on the San Bruno fault-line, and none of them are far from it, so that if there had been any movement along that line, these would certainly have suffered more.

South San Francisco and the meat packers' establishments are on a different geological foundation from the towns previously mentioned. These places rest almost directly upon the old Franciscan rocks, with only a thin layer of sand on top of them in places. This makes a much firmer foundation than is found at the other places, which are situated upon a considerable thickness of sand or gravel.

The buckling of the tracks of the South San Francisco car line between the town and San Bruno Point, where the chimneys mentioned are located, is significant of the contrast in the intensity of the shock at the two places. The rails are bent and broken in a number of places, where the track crosses the marsh between the two places. The difference of intensity is striking when it is taken into consideration how close they are together.

From South San Francisco to San Bruno, there is a line of big steel water-mains, supported on a trestle frame, where it crosses the marsh. This line did not break, but was bent and twisted into S-shaped figures.

North of San Bruno Point, at the Southern Pacific tunnel along the bay shore cut-off, no damage was done, except for the sliding and settling of the débris in the newly filled area.

The cemeteries. — The San Bruno fault-line was followed all the way from South San Francisco to the cemeteries. There was absolutely nothing to indicate any movement along that line at the time of the earthquake.

The cemeteries between Baden and Colma suffered very severely from the shock. It was estimated that in Holy Cross Cemetery (plate 96B) over 75 per cent of all the monuments were either thrown down or twisted on their bases. Plate 97A shows a typical

case of a monument overthrown. In a few cases monuments were snapt off. In one instance a single piece about 3 inches thick was broken off by the shock. The upper part of the slab is in two pieces, tho the second break may have been made when the slab fell. The stone chapels at several cemeteries were badly shaken and partially wrecked.

There is one monument in Holy Cross Cemetery that was composed of several pieces, the top piece being the figure of an angel. Underneath this angel was a small thin piece of stone beveled to meet the base of the figure, and below that was a block of about 20 inches square and 12 inches thick. It was observed that the washer and the square block were inverted in their positions. It is stated that this displacement and inversion of these blocks was effected by the earthquake. If so, there must have been enough upward motion to throw this block and washer high enough to turn completely over.

There was no consistency apparent in the direction in which monuments fell; they seem to have fallen in every direction.

The other cemeteries all suffered about the same, but the percentage of fallen monuments was not nearly so high in the others as it was in the Holy Cross Cemetery. The reason for this difference in the number of monuments overthrown is not apparent; the soil of all these cemeteries is practically the same. A possible reason is that the difference in effects is due to a difference in the depth of the sand upon the underlying rock floor, and that there was a greater depth of sand underneath the Holy Cross Cemetery. There is no proof of this, however.

Plate 95A and B illustrates the wreck of buildings at the Woodlawn and Hills of Eternity Cemeteries.

On top of the gate posts at Holy Cross, there were two large ornamental stone balls. These were fastened to the posts by steel rods projecting up into them; these rods, however, did not hold them in place and the balls were both thrown down. West of the gates the stone railroad station was badly wrecked, fully one-third of it being shaken down. Between the depot and the gates small 1-inch water-pipes, running in a northeast-southwest direction, were bowed upward and forced out of the ground. In relaying the pipes, they were not set more than 1 foot deep, from which it is inferred that they were probably not more than 1 foot deep before the earthquake.

In front of the Holy Cross railway station (plate 96A) the tracks of the main line of the Southern Pacific were slightly bent, but the lighter rails of a side track near by were much more disturbed. Around the station the ground had settled and there were a number of cracks, from 4 to 6 inches wide, but these were probably due to the fact that this ground had been filled in to get the required grade for tracks and the station.

Landslides. — North of Holy Cross Station, by a little lake west of the cemetery, there was a large landslide along the roadbed of the Southern Pacific Railway. For about 300 feet the bed caved and in one place the west track was left suspended in the air. West of the railroad there were large cracks in the newly filled grounds of the Woodlawn Cemetery.

One hundred feet west of the Southern Pacific Railroad track is the electric line of the United Railroads between San Mateo and San Francisco. This roadbed was also filled in considerably for the required grade, and was not as well settled as the Southern Pacific tracks, so it suffered more severely. West of the Holy Cross Cemetery, the rails were distorted and pulled apart 3 or 4 inches at the joints, due mainly to the dropping of the roadbed. Poles were out of true, but no wires were seen broken from tension or the swaying of the poles.

Northeast of Mount Olivet Cemetery there was an earth-flow in the sandy soil at the base of the San Bruno Mountains. The angle at which the materials slid was hardly more than 10 degrees. The sand and water forming this slide came out of a hole several hundred feet long and 150 feet wide, flowed down the hill several hundred yards toward

the cemetery, carried away a pile of lumber, and knocked the power-house from its foundations. The front of the mud-flow piled up in a bank when it reached the nearly level ground, and dammed up the mass behind it. The earth was harder several weeks later than it must have been at the time of the flow, but it was still slushy and there was still a little water flowing along the path of the earth-flow, coming from a small spring where the slide originated.

On the west bank of a creek, near and parallel to the line of the railroad southwest of Holy Cross Cemetery, there was a crack several hundred feet long. This was along the bank near the creek bed and was an incipient landslide.

On the east edge of the hills west of the Chinese Cemetery and 9-mile house, a line of cracks extends for a distance of about 1,000 yards. These cracks are more than a foot wide in places, and there is an apparent downthrow on the northeast; in one place there is a long line of crusht earth, such as occurs along the main fault-line. Inspection showed that these cracks were caused by a slight landslide. The line of crumbled earth was due to the earth above it on the hillside sliding slightly, and the crumbling represented a line of buckling of the crust.

These cracks are upon the top of a hill, at an elevation of about 400 feet; their general direction is about N. 40° W., and parallel to the San Andreas fault, and the line of hills here has the same general trend.

A line along the east edge of the hills, then, would naturally have the same trend as that of the main fault. A continuation of these cracks would go to the ocean thru Wood's Gulch, which is along the line of a small fault; but no evidence could be found showing any visible movement at the time of the late earthquake. There were several large landslides on both the southwest and northeast sides of the gulch, and at the ocean the amount of dirt that had fallen was very large. These things show a high earthquake intensity, but there is no evidence of other movement.

The coast north of Mussel Rock. — Along the coast from Mussel Rock to Lake Merced the section known as Seven Mile Beach presented steep cliffs from 1 to 700 feet in height. These cliffs are composed of the beds of the Merced series, which are soft clay and sandstones only partially consolidated. Along the face of these cliffs the Ocean Shore Railway had started a grade at an elevation of about 300 feet above tide level. Along this bluff a large amount of earth slid down the slopes at the time of the shock. This caving of the banks was due to the nature of the soil, the proximity to the fault-zone, and the disturbance of natural slopes due to the railroad terrace near the top.

In places this slope toward the ocean was brought about to the angle of the repose of this material and the roadbed was entirely destroyed for a distance of 3 miles.

On April 25, the writer was on the edge of the cliffs near Wood's Gulch. About 3 P.M. of that day there was a shock with an intensity estimated to be between VI and VII. At that time the cliffs shook like so much gelatine, and it was necessary to hold on to prevent falling. On the north side of the canyon, hundreds of tons of earth fell even with this light shock.

Along the top of the cliffs large cracks were formed to a distance of several hundred feet from the edge. Many of these cracks were a foot or even as much as 3 feet in width, and small scarps were often present, 4 or 5 feet high and 20 or 30 yards long. The general tendency was for everything to slide into the ocean, but this was not always true. Miniature scarps of more than 6 feet were seen with a downthrow upon the northeast or inland side. The Merced beds, as a whole, were badly shaken, and broke up all along the coast section. Near Mussel Rock part of the roadbed slid for about 500 feet and on the hillside above the road there was a long crack which was the beginning of a slide that might have taken a large part of the hill. The direction of this crack was about N. 45° W., which is more toward the north than the fault-line at this particular place.

A. Woodlawn Cemetery, south of San Francisco. A. C. L.

B. Hills of Eternity Cemetery, south of San Francisco. All four gables thrown out. Parapets thrown in on roof. A. C. L.

A. Holy Cross Cemetery Station, south of San Francisco. Building on made ground. A. C. L.

B. Holy Cross Cemetery, south of San Francisco. A. C. L.

A. Overthrown monument, Holy Cross Cemetery. R. B. M.

B. Brick building and high chimney left standing. South San Francisco. R. B. M.

C. Roadbed and rails of electric railway on marsh west of San Bruno. R. B. M.

D. Roadbed and rails of electric railway between Baden and San Bruno. R. B. M.

A. Wreck of 1-story brick railway warehouse, San Mateo. Per J. C. B.

B. Brick stable, San Mateo. Upper story was thrown out and roof dropt one story. Per J. C. B.

Lake Merced. — About 6 miles north of Mussel Rock, where the Merced beds disappear under æolian sands, the disturbance seems to have been quite violent. An old railroad trestle, that crosses the northern end of Lake Merced in the narrowest place, was badly wrecked. This bridge was broken in two places, and the intermediate piece was out of line with both ends. The direction of the offsets was very nearly due north and south. At one break the west piece was shoved 12 or 14 feet past the other section. The west end of the intermediate piece failed to join the section at the west bank by 6 or 7 feet. The west section that remained with the bank was from 4 to 5 feet lower vertically than the intermediate piece. The trestle was old, built of heavy timbers on a sharp curve, and not in use, which will in part account for its destruction. The swaying of this bridge destroyed a section of it 50 to 60 feet long. On the hillside where this trestle reaches the west bank of the lake, cracks parallel to the shore line suggest the cause of the destruction of the bridge. The displacements here are larger than any along the main fault-line, and it is apparently entirely local, due to the slipping and settling of the west bank of the lake.

Upon following around the north end of the lake to the road that runs to the Life Saving Station, a line of terra-cotta pipe, about 8 inches in diameter, was found. There was no large displacement found in this pipe, altho it had been cracked at many points. There is nothing in these phenomena to show that there was a fault thru the Merced Valley.

Just south of the bridge across Lake Merced, a sand-bar was forced up out of the lake, from water that was previously 6 or 8 feet deep. This bar is parallel to the west bank of the lake, and has a direction almost due north and south. This was probably caused by the same thing that wrecked the bridge; that is, the displacement and settling of the west bank of the lake at the time of the earthquake.

THE AREA SOUTHWEST OF THE SAN ANDREAS FAULT.

Difference of apparent intensity on the two sides of the fault. — On passing from the beds of the Merced series on the northeast to the southwest side of the fault, there is a marked difference between the distribution of small cracks and little earthslides. On the northeast side, in the Merced beds, these cracks and landslides are common, but on the southwest side they are entirely absent. This can hardly be taken to show that there was any difference in intensity on the two sides of the fault; it is probably the result of the difference in the character and stability of the rocks. At other places north of the fault, but southeast of the Merced beds, this difference has not been noticed, probably because in that part of the area the rocks are nearly all Franciscan.

On the south side of the San Andreas fault there are no towns affording an opportunity for judging the intensity of the shock. The gradation must of necessity be based upon something else. Landslides occur both near the fault-zone and at a distance from it, under somewhat similar geologic and topographic conditions. It seems to be a fair assumption that a landslide is indicative of a high intensity.

Laguna Salada Valley. — In the valley of Laguna Salada, the Ocean Shore Railroad had a temporary trestle erected for making a fill in the valley up to required grade. This trestle was twisted and thrown out of line, and the earth sank along the newly filled roadbed. Similar things happened to newly filled roadbeds along the west edge of the Santa Clara Valley, near Baden and San Bruno.

Along the base of the cliffs south of Laguna Salada, there were several small slides, some from the face of the hills and others in the newly graded roadbed. There were many small cracks along the tops of the cliff, parallel to its edge, showing that the face of the bluff was shattered, and that more earth might slide. One big rock pinnacle, which had been left above the roadbed as a landmark, and which had seemed a little dangerous before, was shaken down.

Calera Valley. — In Calera Valley the shock was severely felt by people in some small temporary shacks. South of this place, in the San Pedro Valley, two old wooden houses showed no structural damage, and only one of two brick chimneys was thrown down.

San Pedro Point. — From San Pedro Point southward for about 1.5 miles, the cliffs rise to heights of from 400 to 800 feet. The railway company had cut a bench for its roadbed several hundred feet above the ocean. This roadbed, being largely in solid rock, was for the most part not much injured; but in some places it was obliterated by rock slides that came from above.

Just north of the point known as Devil's Slide, there was a landslide of the whole face of the west end of Montara Mountain. It started at about 800 feet above the sea, and swept down carrying many hundred feet of roadbed along with it. The material that slid was sandstone and granite, but it seemed to be much weathered and softened in places, so that it was loose ground.

South from the Devil's Slide to the first small coast valley, there were landslides along the cliffs. The rock in this vicinity is massive granite, but the landslides showed that the rock had disintegrated for a considerable distance below the surface and the slides were in this decomposed rock. Wherever the railway bed was filled or built out with this material, there was more or less sliding and settling, caused by the earthquake.

Montara Point. — The old, low brick structure at Montara Point did not show any effects of the shock, but there was some damage to a wooden tank-house. One of the tanks, which was previously known to be old and rotten, collapsed entirely. In the yard of the keeper is a concrete water cistern which holds over 6,000 gallons, and which is set flush with the ground and protected with an iron cover that two men can hardly lift. At the time of the shock this tank was almost full and had the cover on. The violence of the shock was sufficient to throw this cover 10 or 15 feet, and spill about 3,000 gallons of the water in all directions.

The observations of the light-house keeper are considerably at variance with what some people have said regarding the behavior of the ocean at the time of the earthquake. Many persons told of waves that had rolled high up on the cliffs. The keeper reports that during the actual period of shaking the ocean was smooth, without even the customary motion. After the shock had ceased, it was perhaps half a minute before the calm was broken and the regular swell began. He reports that he was upon his feet at the time of the shock, and altho used to being on shipboard, could stand only with great difficulty.

This testimony as to the appearance of the water is almost the same as that of the light-house keeper at San Mateo Point. There was no evidence anywhere along the coast to show that the water rose above tide-level.

On the southwest face of Montara Mountain, nearly all of which is visible from the road, no landslides of any size were observed.

Landslides. — South of Montara Point, in the low foot-hills north of Half Moon Bay, there were two large low-angle landslides or earth-flows. One of these landslides was on the low foot-hills facing the ocean; the other on the northeast bank of Frenchman's Creek, several miles northeast of Half Moon Bay.[1]

From Half Moon Bay to San Mateo, there were several large slides of different character from those already mentioned. These resulted from the slipping of large masses of rock, many of the fragments in one of the slides being over 20 feet in diameter. (See plates 124c and 126B.)

On the south face of Scarper Peak, and on the southwest face of Ox Hill, there were several landslides both large and small. No photographs of the larger slides are available.

About 4 miles east of Half Moon Bay, just off the south edge of the San Mateo sheet, there was another large earth-slide similar to the two already mentioned.

[1] These are described by Mr. R. Anderson in the section dealing with Earth-flows.

Pilarcitos Canyon. — In Pilarcitos Canyon, the stone dam of the artificial lake was uninjured and the flume down the canyon sprung only a few leaks. Mr. Ebright's house, at the lower end of the lake, lost two out of three chimneys by the shock. The spring water at this place, which is used for house supply, is said to have been milky-white during the day of the earthquake. This canyon is made by one of the large faults mentioned in the first part of the paper. If there had been any movement along this fault, it would have been shown at the dam which crosses the canyon at a right angle to the fault-line.

Cahill's Ridge. — This range of hills forms the northeast side of Pilarcitos Canyon, and is the second ridge southwest of Crystal Springs Lake, with the same general northwest-southeast trend. On the top of this ridge, a small house lost one of two chimneys, and things inside were shaken around. A table is said to have tilted enough for dishes to slide off.

Just southeast of the house is a depression in the ridge, across which furrows and cracks formed similar to those along the main fault-line, but not extending more than several hundred feet. These cracks do not seem to have been landslide cracks, for they are on top of the ridge and on a flat piece of ground.

Another peculiar phenomenon was observed upon Cahill's Ridge, less than 1 mile northwest of the cracks mentioned. In an area of limestone, a small patch some 30 feet in diameter was torn up as tho it had been plowed and harrowed, and no large pieces of sod were left intact. Around this in various places were cracks of a few inches in width, with one or two over a foot wide. There was a slight downthrow on the uphill side to be noticed in some of these cracks, which eliminated the possibility that they were cracks preparatory to landsliding.

Sawyer's Ridge. — On Sawyer's Ridge, about 9 miles north of the region described on Cahill's Ridge, there were cracks several hundred feet long almost at the top of the ridge. These were parallel to the line of the main fault, which is a mile to the east, and there was a marked downthrow of from 2 to 3 inches on the southwest side, which in this case was the uphill side. If the downthrow were on the downhill side, then it could be possible that these were landslide cracks. The exact cause or mode of the formation of these cracks, or the breaking of the ground on Cahill's Ridge, is not clear.

In the canyon between Sawyer's Ridge and Sweeney's Ridge, a 2-story wooden house did not suffer much, and out of 4 chimneys only 2 were cracked. One of those that remained standing was a tall top-heavy chimney of brick; the other was only a tin pipe.

At Byrne's store, on the Half Moon Bay road, half a mile west of Crystal Springs Lake, it was reported by the keeper that the water from their spring, on the day of the shock, was muddy and was not tasted. On the second day after the earthquake, it had a very salty taste, but on the third day was normal. A house on the northwest side of Half Moon Bay road, 2,000 feet southwest of the dam, was thrown from its foundations, while some 200 feet northwest of this house there was a slide in the canyon.

CONCLUSIONS.

There was no marked difference of intensity on the two sides of San Andreas fault-line.

There was a decrease of intensity on both sides of the fault-line, as one goes away from it.

The distribution of intensity bears no evident relation to the minor faults or structure of this area.

It is evident that the intensity varies with the geology, or with the areal distribution of rocks and soils.

The areas that suffered most severely were those upon filled ground.

Areas upon marshy ground showed destructive effects similar to artificial filled land.

Next in intensity to areas of filled land are those upon incoherent sands. The damage in sandy areas was due partly to the shaking of sand like jelly and partly to settling and sliding.

Areas that suffered least were upon rock of some kind in place.

Towns along the west edge of the Santa Clara Valley, at equal distances from the fault-line and upon similar geological formation, showed the same intensity.

The waters of the bay and of the ocean were quieted by the shock, and there was no perceptible tidal wave following the movement.

The shock was not felt as strongly upon the waters of the bay as upon the land near by.

There was an unusual flow of water in the creeks draining into the bay near Baden and San Bruno, directly after the shock.

The destruction of buildings and the disturbance of railway roadbeds and rails was much more violent thruout the area covered by the incoherent Merced beds than on the older hard rock in the adjoining areas.

There was a large amount of damage done in the cemeteries, which are on æolian sands.

A large number of the monuments fell at the cemeteries, but there was no consistency in the direction of falling to show the direction of motion.

Motion in more than one direction was suggested by monuments twisted upon their bases. Vertical motion was shown in one monument which had the upper portion turned upside down.

NOTES BY OTHER OBSERVERS.

San Mateo, San Mateo County (Mr. Maxwell). — At the time of the shock Mr. Maxwell had led a horse out of the barn to give him water. He first heard a heavy rumble, which he took for thunder, coming from the northwest. This was followed by a wavy motion of the ground. The earth rose and fell like the swell of the sea, the waves being about 3 feet high. A water-tank about 30 feet high tipt over to the southeast so as to throw water out and allow him to look into the top of the tank, he being 75 or 80 feet distant The tank swayed back to its place without falling. The two wave motions were followed by a severe shock, as if the waves from the northwest and southeast met suddenly under him. Both he and his horse were thrown off their feet. The horse attempted to run, but could not on account of the violent motion of the earth.

Redwood (E. C. Jones). — The mains of the gas plant are all of steel and suffered no damage. The gas-generating apparatus was moved several inches on its foundation, and all cast-iron connections were more or less damaged. The buildings, being of frame and corrugated iron, were not seriously damaged. A 20,000-foot gas-holder in a redwood tank above ground was completely demolished by the earthquake. The shock seems to have been particularly severe at Redwood City, and the boiler settings at this station were badly damaged, while at San Mateo, 9 miles distant, the settings were uninjured.